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PARTICULATE CONTROL MOBILE TEST UNITS: FIRST YEAR'S OPERATION

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Monsanto Research Corporation

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This report summarizes the first year of operation of EPA-owned mobile test units that are being used in the field to study the applicability of different control methods to the control of fine particulate emitted from a wide variety of sources. Two mobile units are described: 1) a fabric filter (baghouse) and 2) a wet scrubber. The latter unit includes two types of wet scrubbers: venturi and sieve tray.

Results from baghouse tests on a coal-fired power plant indicate suitability of a baghouse, with woven glass bags, for control of dust from this type of source. Results from tests on a pulp mill lime recovery kiln show high dust removal efficiency, but the associated high moisture content of the gases portends operating problems sufficient to indicate that a baghouse would be unsuitable for control of dust from this source.

Operation of the mobile scrubber unit during the year was confined to startup testing and correction of mechanical and operating difficulties.

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The Project Officer, Mr. Dale L. Harmon, provided valuable assistance in negotiating entrance to the test sites, in interfacing with the mobile unit fabrication contractors, and in helpful suggestions regarding test plans.

I. CONCLUSIONS

Operating on a coal-fired power plant, baghouse cleaning-mode/bag-type combinations can be ranked in descending order of collection efficiency as follows:

1) Reverse clean - Nomex felt bag

2) Reverse clean - Glass bag

3) Shake clean - Nomex felt bag

4) Shake clean - Nomex woven bag

5) Pulse clean - Nomex felt bag

In general, the more efficient the cleaning mode, the poorer the filtration; or, the less a bag is cleaned, the better it filters.

In general, the more difficult a bag is to clean, the better it filters.

The smaller the fiber size in a bag fabric, the better its retention of fine particles.

The more disoriented the bag fabric structure, e.g., felt vs. woven, the more difficult the bag is to clean, consequently the better it filters. This may include surface disorientation, such as napping.

Although the relative humidity level has not been established, it seems clear that for dust sources with associated high moisture content, operating problems engendered by condensation will make baghouse control of dust impractical, e.g., pulp mill lime recovery kiln.

II. RECOMMENDATIONS

1. The need exists for review and evaluation of presently used particulate sampling techniques in regard to the usefulness of results obtained in relation to program objectives.

2. It appears that repackaging and upgrading the baghouse unit could improve the cost-effectiveness of the field program.

3. A study of the present design and system configuration of the scrubber unit could result in beneficial revisions leading to improvement in cost-effectiveness of the field program.

III. INTRODUCTION AND OBJECTIVES

The purpose of this contract is to provide the operational effort required to obtain field, laboratory, and pilot plant test data from three types of EPA-owned equipment and systems: 1) mobile test units; 2) an aerodynamic test chamber; and 3) a model pilot SO_x scrubber.

The mobile test units consist of truck-mounted items of conventional dust collection equipment: fabric filter (baghouse), venturi scrubber, sieve tray scrubber. A fourth item, currently in design stage, will be an electrostatic precipitator. The main objective is to assess the ease or difficulty associated with this type of equipment in control of particulate of varying characteristics obtained at different types of emission sources in the field.

The wind-tunnel-like aerodynamic test chamber provides for gas movement in a wide range of velocities at temperatures from ambient to above 150°C and a broad spectrum of gas composition and particulate loading. The objectives for its use are calibration of fine particulate measurement equipment, and characterization of the capabilities of commercially available, pilot-scale, fine particulate control equipment and devices.

The model pilot SO_x scrubber consists of twin, 23-cm diameter scrubbers and associated systems capable of several types of scrubbing modes operating in parallel or series. The objective of their operation is to find quick, easy, inexpensive solutions to operating and technical problems encountered in the development of full-size SO_x scrubbing systems.

The aerodynamic test chamber and model pilot scrubber system are semi-permanent installations at the Environmental Research Center at Research Triangle Park, N. C. Although the mobile units use this location as a service base, the majority of their operating time is spent in the field at various plant sites about the country.

The three operational areas represent, to varying degrees, different program interests, and up to now, different groups or sections within the Industrial Environmental Research Laboratory. The contractor's primary objective is to fulfill the needs of each interest within the contract scope. Thus, his involvement varies a little in each operational area. For example, in the areas of the aerodynamic

test chamber and pilot SO_x scrubbers, program and test planning, and interpretation of results activities are mainly conducted by EPA personnel. The contractor schedules and executes the test plans per specified conditions, and collects and reduces data to usable form. The nature of the current program, especially the pilot SO_x scrubber program, dictates this type of relationship. On the other hand, in the mobile test unit area, the contractor is also largely responsible for developing the test plans and interpreting the results obtained.

This report summarizes operation of the mobile baghouse and scrubber units during the first contract year. The baghouse unit operated in the field evaluation program essentially the entire year. Delayed receipt of the scrubber unit, occasioned by slower than expected delivery of materials during fabrication, plus mechanical difficulties that emerged during startup testing have frustrated attempts to start the field evaluation program with this unit.

IV. REVIEW OF OPERATIONS

BAGHOUSE UNIT

Background

The mobile fabric filter system (baghouse unit) was designed and fabricated by GCA/Technology Division, Bedford, Mass. The unit, mounted on a 1360 kg truck, is described at length in GCA reports (Ref. 1, 2). Briefly, it has the following capabilities:

- Filtration can be conducted at cloth velocities as high as 0.102 m/s with a pressure differential up to 51 cm of water and at gas temperatures up to 288°C.
- The mobile system can be adapted to cleaning by mechanical shaking, pulse jet, or low pressure reverse flow, with cleaning parameters varied over broad ranges.
- The system can be operated in a series filtration mode.
- One to seven filter bags of any media, 1.22 to 3.05 meters long and up to 30 cm in diameter may be used.
- Automatic instruments and controls permit 24-hour operation of the system.

After brief field tests, the unit was delivered to present contractor personnel for use in a large field testing program for the Industrial Environmental Research Laboratory of EPA.

For several reasons, the baghouse unit, as received, required preliminary "dry run" testing at the RTP Environmental Research Center, and intensive shakedown tests in the field under severe conditions. The dry run tests at RTP were directed at operational check of system components and training of new operators.

Following this, the unit was given intensive shakedown tests in the field on a pulp mill lime recovery kiln. After a brief return to RTP for refurbishing, the unit was taken to Sunbury, Pa., for tests on Pennsylvania Power and Light Company's Shamokin Dam, coal fired, generating station.

On completion of these tests, about two months were required to refurbish the unit and sample trains, after which the unit was placed at a lime recovery kiln at Weyerhauser Corporation's pulp mill in Plymouth, N. C. At this writing, the unit is in final phases of testing on the lime kiln and will next move to a recovery furnace at the same plant.

Shakedown Tests

The dry run tests at RTP revealed a number of operational deficiencies, none of which appeared particularly serious. While these deficiencies were readily corrected, the question persisted of performance reliability and durability under severe, protracted field conditions, since all systems operating in an integrated mode could not be checked in dry run tests.

For field shakedown testing, the unit was attached to a pulp mill lime recovery kiln. A host of difficulties ensued. These are noted, along with remedial actions, in Appendix A, which also lists operational difficulties encountered subsequently at Sunbury and on return to Plymouth. Figures 1 and 2 show the unit on site at Plymouth.

Sunbury Tests

Details of testing at Sunbury were reported in a special technical operations report for that site, and operational difficulties, as noted above, appear in Appendix A.

Three types of bags and three cleaning modes were tested:

Bag Type: Glass
Nomex Woven
Nomex Felted

Cleaning Mode: Shake
Pulse
Reverse

Test plans proposed for each cleaning mode with each bag type are shown in Tables 1 - 3. Time restraints imposed by lengthy sampling periods and availability of the test site resulted in adoption of the compromise test plan shown in Table 4. Throughout the tables and graphs that follow,

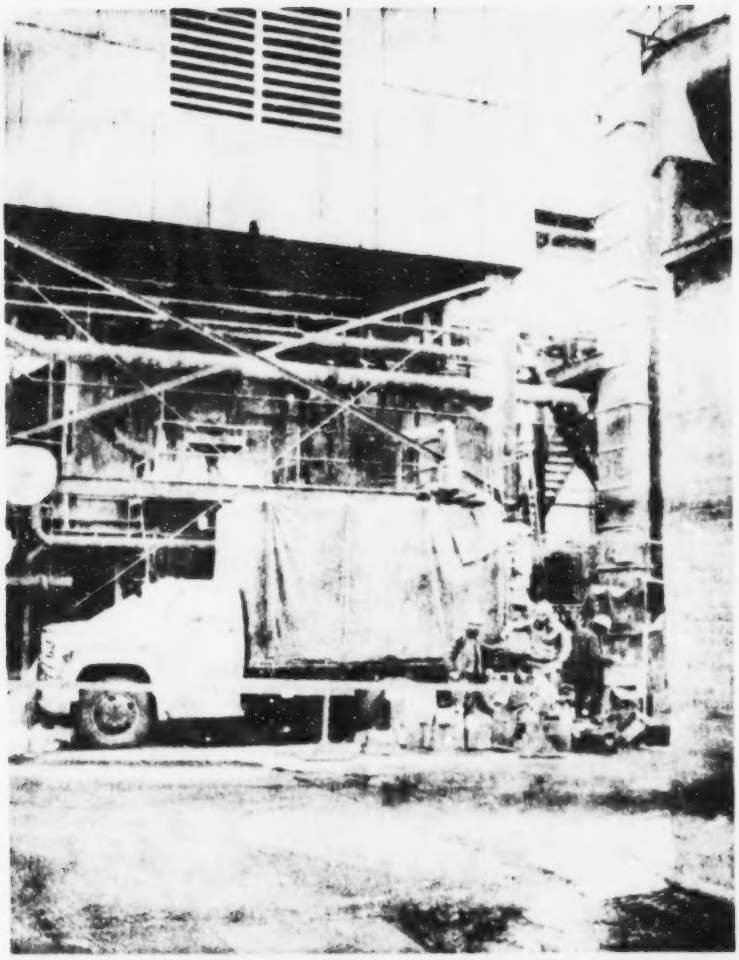

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Figure 1. Baghouse Unit on Site
at Plymouth, N.C.

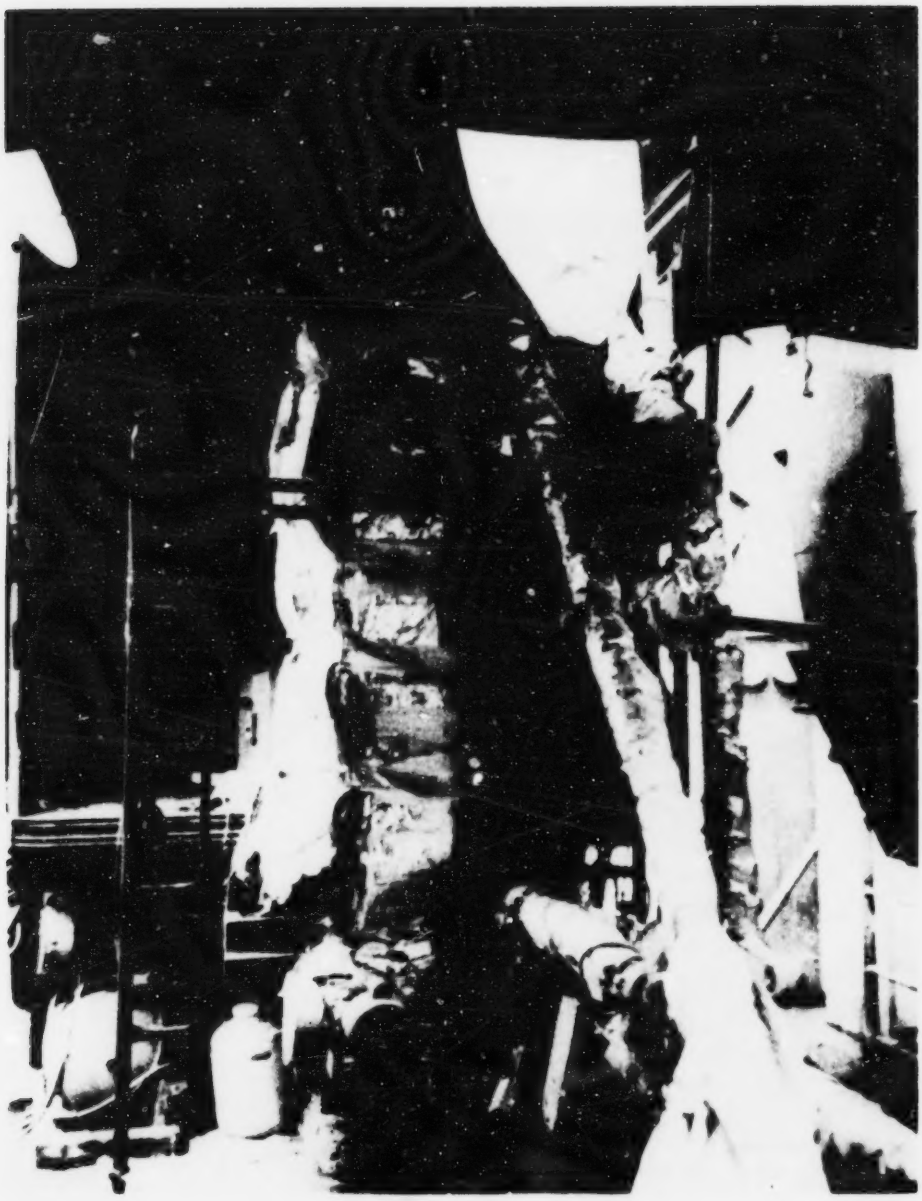

Figure 2. Baghouse Unit on Site at Plymouth, N.C.

Table 1. PROPOSED TEST PLAN-
SHAKE MODE

Series 1

Variable: Air/Cloth ratio (A/C)

A/C range: 0.005 - 0.041 m/s

Test values: 0.005, 0.010, 0.020, 0.030, 0.041 m/s

All other parameters at standard conditions.

Series 2

Variable: Filtration period

Test values: 10, 20, 30 min

Use optimum A/C determined above. All other parameters at standard conditions.

Series 3

Variable: Cleaning (shake) period

Test values: 5, 10, 20, 30, 60 sec

Use optimum A/C and filtration period determined above. All other parameters at standard conditions.

Standard Conditions

Filtration period	20 min
1st pause	10 sec
Cleaning period	10 sec
2nd pause	30 sec
Shake frequency	7 cps
Amplitude	2.22 cm
Shaker-arm acceleration	4.4 g's
Bag tension	0.682 kg
A/C	0.02 m/s

Table 2. PROPOSED TEST PLAN-
PULSE MODE

Series 1

Variable: Air/Cloth ratio (A/C)

A/C range: 0.010 - 0.102 m/s

Test values: 0.010, 0.020, 0.030, 0.041, 0.0508, 0.076, 0.102 m/s

All other parameters at standard conditions.

Series 2

Variable: Pulse jet pressure

Test values: (2.76, 3.45, 4.14, 4.83, 5.52, 6.21) x 10^5 Pa

Use optimum A/C determined above. All other parameters at standard conditions.

Series 3

Variable: Pulse interval

Test values: 15, 30, 60, 90, 120 sec

Use optimum A/C and pulse jet pressure determined above. All other parameters at standard conditions.

Standard Conditions

Pulse interval	60 sec
Pulse duration	0.10 sec
Pulse jet pressure	4.14 x 10^5 Pa
A/C	0.020 m/s

Table 3. PROPOSED TEST PLAN-
REVERSE MODE

Series 1

Variable: Air/Cloth ratio (A/C)

A/C range: 0.005 - 0.041 m/s

Test values: 0.005, 0.010, 0.020, 0.030, 0.041 m/s

All other parameters at standard conditions.

Series 2

Variable: Filtration period

Test values: 20, 30, 40 min

Use optimum A/C determined above. All other parameters at standard conditions.

Series 3

Variable: Cleaning (reverse) period

Test values: 5, 10, 20, 20, 60 sec

Use optimum A/C and filtration period determined above. All other parameters at standard conditions.

Standard Conditions

Filtration period	30 min
1st pause	10 sec
Cleaning period	10 sec
2nd pause	30 sec
Bag tension	0.682 kg
A/C	0.02 m/s
R. F. air rate	0.047 m^3/s

Table 4. ACTUAL RUN CONDITIONS

SHAKE MODE

Filtration period	20 min
1st pause	10 sec
Cleaning period	10 sec
2nd pause	30 sec
Shake frequency	7 cps
Amplitude	2.22 cm
Shaker-arm acceleration	4.4 g's
Bag tension	0.682 kg
A/C	0.010, 0.015, 0.020 m/s

PULSE MODE

Pulse interval	1, 2, 3 min
Pulse duration	0.10 sec
Pulse jet pressure	4.14×10^5 Pa
A/C	0.020, 0.031 (max.) m/s

REVERSE MODE

Filtration period	30, 40, 50 min
1st pause	30 sec
Cleaning period	20 sec
2nd pause	30 sec
Bag tension	0.682 kg
A/C	0.010, 0.015, 0.020 m/s
R. F. air rate	0.045 m^3/s

sample runs are identified by a code composed of the following:

First letter = Cleaning Mode: S - Shake

P - Pulse

R - Reverse

Second letter = Bag Type: G - Glass

NW - Nomex Woven

NF - Nomex Felted

First Number = A/C ratio, fpm (x 5.08×10^{-3} = m/sec)

Second Number = Filtration Period, min, for shake and reverse

= Pulse interval, sec, for pulse

Within the reliability of the sampling techniques, test data precision was generally good. Overall collection efficiency was derived from two sources: total mass sampler, and impactor total mass. Results from each source are shown in Tables 5 and 6. Of these, the total mass sampler results are believed to be more accurate since there are some known loss errors associated with the impactor total mass results. By either method, however, efficiency appears to be quite good.

The data and discussion related to size distribution, too voluminous for this report, are summarized in Tables 7 through 12 in the form of percent penetration by particle size, grouped to show, by cleaning mode and bag type:

-Effect of A/C ratio,

-Effect of pulse interval, and

-Effect of filtration period

on penetration by particle size. This information is shown graphically in Appendix B.

The mean particle size for each sample run is shown in Table 13, wherein also are the arithmetic averages of grouped inlet values and outlet values for each operating mode, and ultimately, the overall average size (geometric

Table 5. TOTAL MASS SAMPLE RESULTS

Run	Mass Loading, mg/m^3 In	Out	Percent Col. Eff.	Penetration
S-G-2-20	2 503	93	96.30	3.70
S-G-3-20	3 108	1	99.97	0.03
S-G-4-20	4 030	207	94.88	5.12
Average	3 213	100	97.05	2.95
S-NW-2-20	5 328	14	99.76	0.24
S-NW-3-20	1 246	1	99.89	0.11
S-NW-4-20	1 898	53	97.23	2.77
Average	2 991	23	98.96	1.04
S-NF-2-20	4 466	1	99.71	0.28
S-NF-3-20	4 818	1	99.98	0.02
S-NF-4-20	5 299	1	99.98	0.02
Average	4 862	1	99.89	0.11
P-NF-4-1	3 858	2	99.94	0.06
P-NF-6.2-1	7 855	35	99.56	0.44
P-NF-6.2-2	6 069	119	98.03	1.97
P-NF-6.2-3	7 525	77	98.97	1.03
Average	6 325	58	99.13	0.88
R-G-2-30	3 616	21	99.42	0.58
R-G-3-30	3 197	9	99.73	0.27
R-G-4-30	3 075	8	99.74	0.26
R-G-4-40	1 509	--	---	--
R-G-4-30	1 960	--	---	--
Average	2 672	13	99.63	0.37

Table 5. TOTAL MASS SAMPLE RESULTS (Cont'd)

Run	Mass Loading, mg/m^3		Percent	
	In	Out	Col. Eff.	Penetration
R-NF-2-30	3 902	1	99.99	0.01
R-NF-3-30	4 122	5	99.88	0.12
R-NF-4-30	4 282	1	99.99	0.01
R-NF-3-40	3 833	--	---	--
R-NF-3-50	4 889	3	99.95	0.05
R-NF-3-30	2 352	1	99.95	0.05
Average	3 896	2	99.95	0.05
Average	3 969	31	99.18	0.82

Table 6. IMPACTOR MASS RESULTS

Run	Mass Loading, mg/m^3 In	Mass Loading, mg/m^3 Out	Percent Col. Eff.	Percent Penetration
S-G-2-20	3 870	--	---	---
S-G-3-20	2 702	--	---	---
S-G-4-20	8 794	--	---	---
Average	5 130			
S-NW-2-20	5 473	4	99.92	0.076
S-NW-3-20	1 695	4	99.79	0.211
S-NW-4-20	2 290	8	99.68	0.325
Average	3 160	5	99.80	0.204
S-NF-2-20	6 549	2	99.96	0.036
S-NF-3-20	2 885	1	99.97	0.035
S-NF-4-20	4 534	2	99.96	0.035
Average	4 649	2	99.96	0.035
P-NF-4-1	1 305	3	99.77	0.233
	1 053	1	99.87	0.134
P-NF-6.2-1	7 351	-	---	---
	1 580	33	97.87	2.13
P-NF-6.2-2	1 786	2	99.89	0.110
	2 725	2	99.93	0.066
P-NF-6.2-3	---	67	---	---
	---	86	---	---
Average	2 634	28	99.47	0.535
R-G-2-30	4 534	1	99.99	0.0025
	4 328	1	99.99	0.0021
R-G-3-30	1 763	1	99.99	0.013
	2 588	1	99.99	0.007
R-G-4-30	1 969	1	99.97	0.031
	1 718	-	---	---
R-G-4-40	1 168	-	---	---
	1 214	1	99.91	0.089
R-G-4-30	985	3	99.74	0.265
	1 168	4	99.66	0.345
Average	2 129	1	99.91	0.094

Table 6. IMPACTOR MASS RESULTS (Cont'd)

Run	Mass Loading, mg/m^3		Percent	
	In	Out	Col. Eff.	Penetration
R-NF-2-30	1 557	1	99.98	0.019
	2 061	1	99.98	0.020
R-NF-3-30	985	4	99.61	0.391
	756	1	99.83	0.166
R-NF-4-30	733	1	99.92	0.079
	1 557	1	99.95	0.047
R-NF-3-40	1 809	1	99.99	0.006
	5 313	1	99.99	0.003
R-NF-3-50	2 290	1	99.99	0.007
	1 031	1	99.94	0.058
R-NF-3-40	962	1	99.93	0.065
Average	1 718	1	99.92	0.078
Average	2 634	7	99.83	0.167

Table 7. PERCENT PENETRATION BY PARTICLE SIZE, SHAKE MODE

Geo. Mean Dia.	S-NW-2	S-NW-3	S-NW-4	Avg.	S-NF-2	S-NF-3	S-NF-4	Avg.
30	0.193	0.0428	0.481	-----	0.554	0.345	0.075	-----
10	0.511	0.0825	0.629	0.408	0.967	1.500	0.0261	0.831
8	0.383	0.0833	0.818	0.428	1.030	1.520	0.0250	0.858
6	0.158	0.0954	0.591	0.281	0.822	0.304	0.0400	0.509
5	0.100	0.0981	0.400	0.199	0.256	0.215	0.100	0.190
4	0.210	0.156	0.183	0.183	0.153	0.135	0.0312	0.106
3	0.166	0.259	0.167	0.197	0.0643	0.0275	0.0200	0.037
2	0.191	0.318	0.221	0.243	0.0826	0.0073	0.0483	0.0597
1	0.177	0.0956	0.318	0.197	0.216	0.015	0.0261	0.0857
0.7	0.267	0.0714	0.271	0.203	1.390	0.0615	0.0944	0.515
AVG.	0.2403	0.2112	0.3998	-----	0.5539	0.4356	0.1140	-----

Table 8. PERCENT PENETRATION BY PARTICLE SIZE, PULSE MODE

Geo. Mean Dia.	P-NF-4-1 Run 1	P-NF-4-1 Run 2	P-NF-62-1 Run 1	P-NF-62-1 Run 2	P-NF-6.2-2 Run 1	P-NF-6.2-2 Run 2	P-NF-6.2-3 Run 1	P-NF-6.2-3 Run 2	Avg.
30	0.405	0.089	0.076	0.94	0.007	-----	3.56		-----
10	0.206	1.13	1.39	2.50	0.015	-----	1.00	2.58	1.103
8	2.00	1.16	5.67	16.30	0.031	0.001	1.27	1.98	3.748
6	1.250	2.75	11.30	28.60	0.024	0.003	0.95	3.55	6.053
5	0.815	2.35	12.30	32.60	0.014	0.007	6.20	3.98	7.283
4	0.682	0.80	4.55	32.80	0.013	0.072	5.82	4.42	6.226
3	0.262	0.10	1.21	9.50	0.180	0.137	4.27	5.24	2.612
2	0.155	0.041	0.95	4.10	0.371	0.343	8.57	10.90	3.179
1	0.121	0.126	11.4	5.29	0.191	0.142	4.89	4.04	3.275
0.7	0.166	0.40	3.65	1.14	0.139	0.090	1.33	1.53	1.056
AVG.	0.629	0.984	5.82	14.75	0.109	0.0994	3.811	4.455	-----
AVG.	0.807		10.3		0.104		4.13		

Table 9. PERCENT PENETRATION BY PARTICLE SIZE, REVERSE FLOW MODE

Effect of A/C Ratio
Glass Bag

Geo. Mean Dia.	R-G-2-30 Run 1	R-G-2-30 Run 2	R-G-3-30 Run 1	R-G-3-30 Run 2	R-G-4-30 Run 1	R-G-4-30 Run 2	R-G-4-30 Run 3	R-G-4-30 Run 4
30	0.00294	0.00286	0.024	0.0106	0.188	0.0857	0.379	-----
10	0.00476	0.00333	0.115	0.0250	0.469	0.125	0.524	-----
8	0.00476	0.00303	0.0836	0.138	0.75	0.183	0.548	0.250
6	0.00476	0.00217	0.0261	0.0769	0.159	0.0695	0.246	0.167
5	0.00434	0.00135	0.0175	0.026	0.073	0.073	0.354	0.139
4	0.0025	0.00059	0.0128	0.0111	0.180	0.360	0.487	0.176
3	0.00115	0.00077	0.0116	0.010	0.0279	0.100	0.486	0.194
2	0.00015	0.00268	0.0187	0.0126	0.0105	0.0127	0.217	0.122
1	0.024	0.0647	0.0182	0.00603	0.0176	0.0241	1.500	0.170
0.7	0.0472	0.052	0.0208	0.012	0.0414	0.048	0.327	0.189
AVG.	0.0104	0.0145	0.0360	0.0353	0.2129	0.1201	-----	0.1759
AVG.	0.0125		0.0357		0.1696			

Table 10. PERCENT PENETRATION BY PARTICLE SIZE, REVERSE FLOW MODE

Effect of Filtration Time
Glass Bag

Geo. Mean Dia.	R-G-4-30 Run 1	R-G-4-30 Run 2	R-G-4-30 Run 3	R-G-4-40 Run 1	R-G-4-40 Run 2
30	0.188	0.0857	-----	0.282	0.480
10	0.469	0.125	-----	0.0795	0.479
8	0.75	0.183	0.250	0.479	0.319
6	0.159	0.0695	0.167	0.00447	0.021
5	0.073	0.073	0.139	0.00434	0.0133
4	0.180	0.36	0.176	0.00444	0.00833
3	0.0279	0.100	0.194	0.00432	0.00432
2	0.0105	0.0127	0.122	0.00250	0.00178
1	0.0176	0.0241	0.17	0.0938	0.0444
0.7	0.0414	0.048	0.189	0.417	0.0469
AVG.	0.2129	0.1201	0.1759	0.0731	0.1126
AVG.		0.1696		0.0929	

Table 11. PERCENT PENETRATION BY PARTICLE SIZE, REVERSE FLOW MODE

Effect of A/C Ratio
Nomex Felt Bag

Geo. Mean Dia.	R-NF-2-30		R-NF-3-30			R-NF-4-30	
	Run 1	Run 2	Run 1	Run 2	Run 3	Run 1	Run 2
30	0.0485	0.1458	7.83	0.0871	0.197	-----	-----
10	0.214	0.143	4.56	0.700	0.429	-----	-----
8	0.0388	0.187	4.09	0.357	0.634	0.0633	0.00344
6	0.00571	0.333	2.45	0.0111	0.060	0.0567	0.00345
5	0.00408	0.184	1.75	0.0231	0.0338	0.0263	0.00351
4	0.00354	0.0291	0.106	0.0426	0.0195	0.0486	0.00368
3	0.00457	0.0149	0.0621	0.0294	0.0259	0.0771	0.0260
2	0.0112	0.0384	0.00917	0.00733	0.0952	0.015	0.0214
1	0.0157	0.008	0.0359	0.291	0.0143	0.0854	0.0310
0.7	0.0222	0.008	0.0727	0.826	0.00526	0.0657	0.005
AVG.	0.0355	0.105	-----	0.254	0.146	0.0548	0.0122
AVG.	0.070			0.200		0.0335	

Table 12. PERCENT PENETRATION BY PARTICLE SIZE, REVERSE FLOW MODE

Effect of Filtration Time
Nomex Felt Bag

Geo. Mean Dia.	R-NF-3-30 Run 1	R-NF-3-30 Run 2	R-NF-3-30 Run 3	R-NF-3-40 Run 1	R-NF-3-40 Run 2	R-NF-3-50 Run 1	R-NF-3-50 Run 2
30	7.83	0.871	0.197	-----	-----	0.140	0.236
10	4.56	0.700	0.429	-----	-----	0.274	0.0752
8	4.09	0.357	0.634	0.00862	0.0109	0.125	0.0666
6	2.45	0.0111	0.060	0.00522	0.0225	0.0363	0.0276
5	1.75	0.0231	0.0338	0.00500	0.0250	0.0277	0.0241
4	0.106	0.0426	0.0195	0.00449	0.0228	0.0456	0.0233
3	0.0621	0.0294	0.0259	0.00333	0.0088	0.0138	0.015
2	0.00917	0.00733	0.0952	0.00217	0.00323	0.0074	0.012
1	0.0359	0.291	0.0143	0.0230	0.00667	0.0162	0.010
0.7	0.0727	0.826	0.00526	0.0970	0.0840	0.00704	0.008
AVG.	-----	0.254	0.1463	0.0186	0.0230	0.0614	0.0567
AVG.		0.200		0.0208		0.0591	

Table 13. MEAN SIZE (GMD), MICRONS

Run	per Run IN	per Run OUT	Average IN	Average OUT
S-G-2-20	10.1	---	10.1	---
S-G-3-20	17.7	---	17.7	---
S-G-4-20	----	---	----	---
S-NW-2-20	27.6	9.66	27.6	9.66
S-NW-3-20	6.98	11.65	6.98	11.65
S-NW-4-20	8.13	7.87	8.13	7.87
S-NF-2-20	55.7	12.7	55.7	12.7
S-NF-3-20	44.7	19.6	44.7	19.6
S-NF-4-20	6.51	10.3	6.51	10.3
P-NF-4-1	9.95	6.82		
	9.45	2.89	9.70	4.85
P-NF-6.2-1	91.9	3.83		
	15.6	3.89	53.7	3.86
P-NF-6.2-2	7.54	2.21		
	5.11	2.13	6.32	2.17
P-NF-6.2-3	-----	3.60		
	-----	4.19	-----	3.89
R-G-2-30	31.4	2.74		
	29.6	3.55	30.5	3.14
R-G-3-30	19.6	9.00		
	20.1	6.97	19.9	7.99
R-G-4-30	13.3	8.53		
	15.6	11.58		
	23.1	9.29	14.0	9.80
R-G-4-40	6.87	18.6	8.08	18.6
	9.23	----		
R-NF-2-30	30.2	7.24		
	56.5	16.1	43.4	11.7
R-NF-3-30	10.6	20.5		
	17.75	17.7		
	7.82	10.1	12.6	16.1

Table 13 (cont'd)

R-NF-4-30	3.85	9.02		
	3.21	11.9	3.53	10.5
R-NF-3-40	5.45	9.22		
	47.3	9.88	26.3	9.55
R-NF-3-50	36.6	12.3		
	16.2	14.4	26.4	13.3
Overall Average.			22.6	9.85

mean diameter) for inlet and outlet.

Analysis of size distribution results leads to the following general statements:

- Based on collection efficiency of particles 5 μ and less in size, cleaning-mode/bag-type combinations can be ranked in descending order of collection efficiency as follows:

  1) Reverse clean - Nomex felt bag

  2) Reverse clean - glass bag

  3) Shake clean - Nomex felt bag

  4) Shake clean - Nomex woven bag

  5) Pulse clean - Nomex felt bag

- The more efficient the cleaning mode, the poorer the filtration, or, inversely, the less the bag is cleaned, the better it filters. Going from poorest to most efficient cleaning mode the ranking is: reverse, shake, pulse.

- The more difficult a bag is to clean, the better it filters. The significant comparison here is between Nomex felt and Nomex woven in shake mode.

- Bag-fabric characteristics have a strong effect on filtration efficiency.

- Fiber size - It is understood that the smaller the fiber diameter in a bag fabric, the greater the retention of small particles. In the present case, an interesting comparison is found between glass fabric and Nomex felt, in reverse cleaning mode. The glass fabric is woven, 200 g/sq m with air permeability of 40 cfm/sq ft. The Nomex felt is 332 g/sq m with permeability of 40 cfm/sq ft. Strictly on this comparison, a considerable difference in performance would be expected. The glass bag, being more open and lighter in weight, should perform worse than the Nomex felt bag, yet data obtained suggest almost equal performance. Assuming both fabrics are made of 3-denier fiber, the Nomex fiber diameter would be about 1.5 times larger than the glass fiber due to the difference in density.

This disparity will be even greater if the glass fiber is less than 3-denier, i.e., the glass fiber will be even smaller in diameter.

- Fabric structure - It is not surprising in present comparisons that the Nomex felt bag outperforms the Nomex woven bag. Fiber size in the two fabrics is likely the same, 3-denier. The woven bag is light, 107 g/sq m, but tightly woven, with permeability of 18 cfm/sq ft. Relative to the woven bag, however, air passages in the felt bag are tortuous, providing frequent opportunity for particle-fiber collision. It is this same character of the felt bag that makes it more difficult to clean.

Though far from rigorous, these statements appear to coincide with reality, i.e., at Sunbury, a full scale baghouse using glass bags and reverse cleaning mode is in satisfactory operation on the generating station. The bag ranking shown above indicates Nomex felt bags may be more efficient but their higher cost for an incremental improvement is unjustifiable.

Plymouth Tests

In view of the time restraints imposed on the program by the lengthy sampling period required to collect a reliable amount of sample in the effluent position, the test plan for Plymouth was again modified. Overall efficiency from total mass sampling was adopted as the prime criterion for evaluating baghouse response to changing test conditions. For each bag/cleaning-mode condition showing best efficiency, size distribution measurements would be made. This approach has the beneficial effect of reducing the time consumed in sampling. The test plan for Plymouth is shown in Table 14.

Early data from Plymouth indicate high collection efficiencies. This is supported by the following. While dust loadings at Plymouth are somewhat higher than those at Sunbury, it is necessary to sample the effluent 7 - 8 hours, compared with 3 - 4 hours at Sunbury, to collect a reliably measurable amount of mass.

It is not sufficient, however, to consider collection efficiency alone as a basis for baghouse application to a pulp mill lime recovery kiln. The high temperature, 204° - 260°C, can be accommodated by glass bags but the high moisture content, over 20%, would be anathema to practical

Table 14. REVISED BAGHOUSE TESTING PROGRAM
(Lime Kiln/Recovery Furnace)
Weyerhaeuser Pulp Mill, Plymouth, N. C.

CLEANING MODE	A/C RATIO		FILTERING TIME (min)		CLEANING TIME (sec)	
	Low	High	Low	High	Low	High
SHAKE	3		30		5	
	3			50	5	
		5	30		5	
	3		30			20
REVERSE	3		30		5	
	3			50	5	
	3		30			20
		5	30		5	

operation of the system. A costly and seldom used preheat and bypass system would be required at each startup of the baghouse, and insulation requirements would be extreme to prevent condensation and deposition of mud on the bags and throughout the system.

SCRUBBER UNIT

Background

The mobile scrubber unit was designed and fabricated by the Detection Branch, Chemical and Biological Sciences Division of the Naval Surface Weapons Center (NSWC), Dahlgren, Va., under Project Order No. 4-0105-(NOL)/EPA - 1AG -133 (D) Task 2. On completion of construction and brief equipment check-out by NSWC, the present contractor received the unit for the Industrial Environmental Research Laboratory on December 16, 1974 and placed it on site at Pennsylvania Power and Light Company's generating station at Sunbury, Pa., for initial field shakedown testing. Shortly after startup of the unit at Sunbury, the induction fans failed and NSWC retrieved the unit to determine the cause of failure and to repair the fans.

On completion of repairs and minor modifications, the unit was returned to IERL (via its contractor) and taken to the Research Triangle Park for extensive shakedown tests under simulated field conditions. Following this, the unit was taken to Weyerhauser Corporation's pulp mill at Plymouth, N. C. and hooked up to a lime recovery kiln for execution of a test plan for evaluating dust control efficiency of the two types of scrubbers involved. At this writing, testing has not begun, pending completion of baghouse unit tests.

Unit Description

The scrubber unit consists of a venturi scrubber and a sieve tray scrubber, together with supporting functional systems housed in the 13.72-meter trailer shown in Figure 3.

A schematic process flow diagram is shown in Figure 4. The system permits operation of either the venturi scrubber or sieve tray scrubber at maximum nominal rate of 0.24 m^3/s gas flow rate. A presaturator is intended to cool and saturate high temperature gas entering to protect heat sensitive elements ahead of the scrubbers and minimize temperature

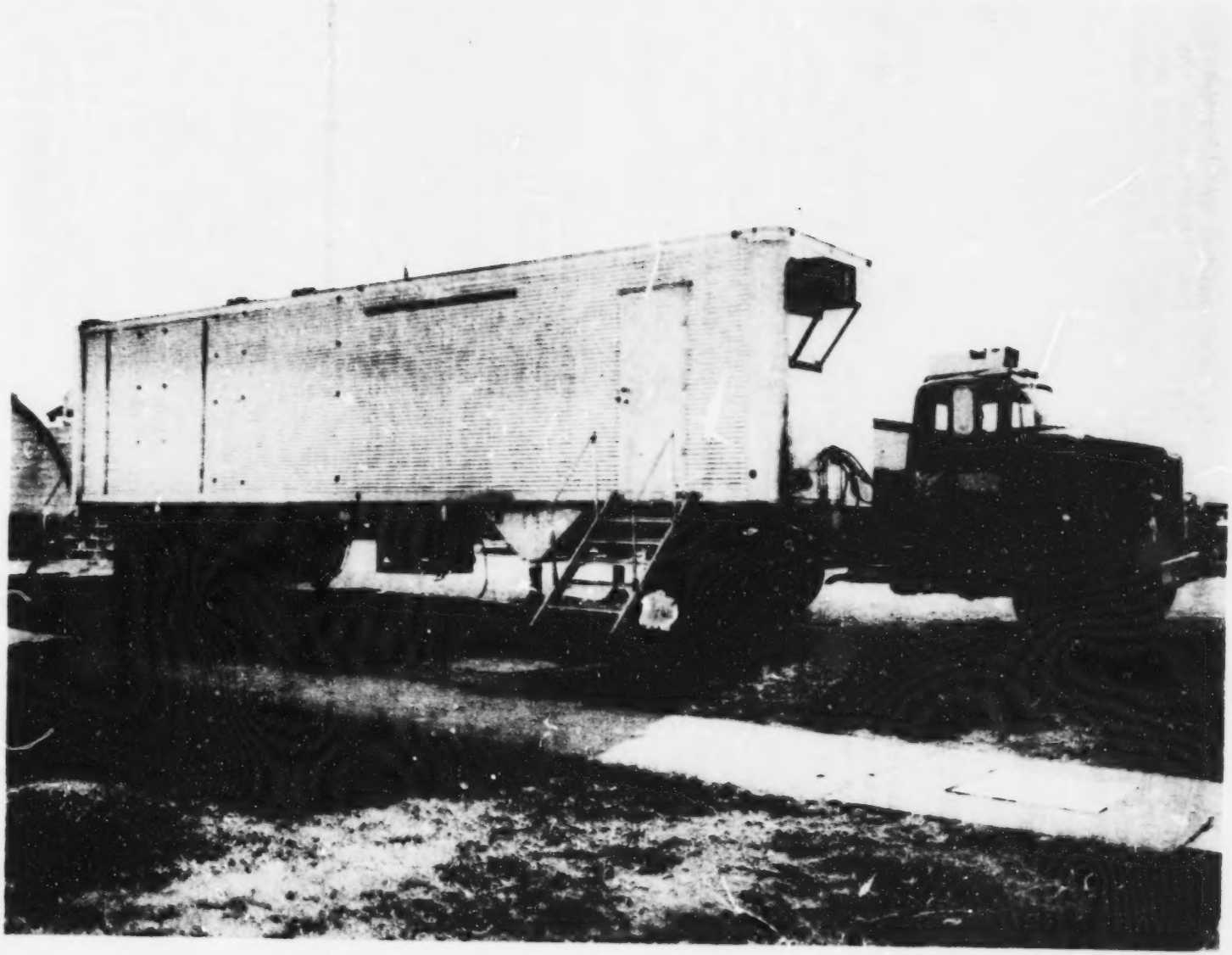

Figure 3. External View of Mobile Scrubber Unit

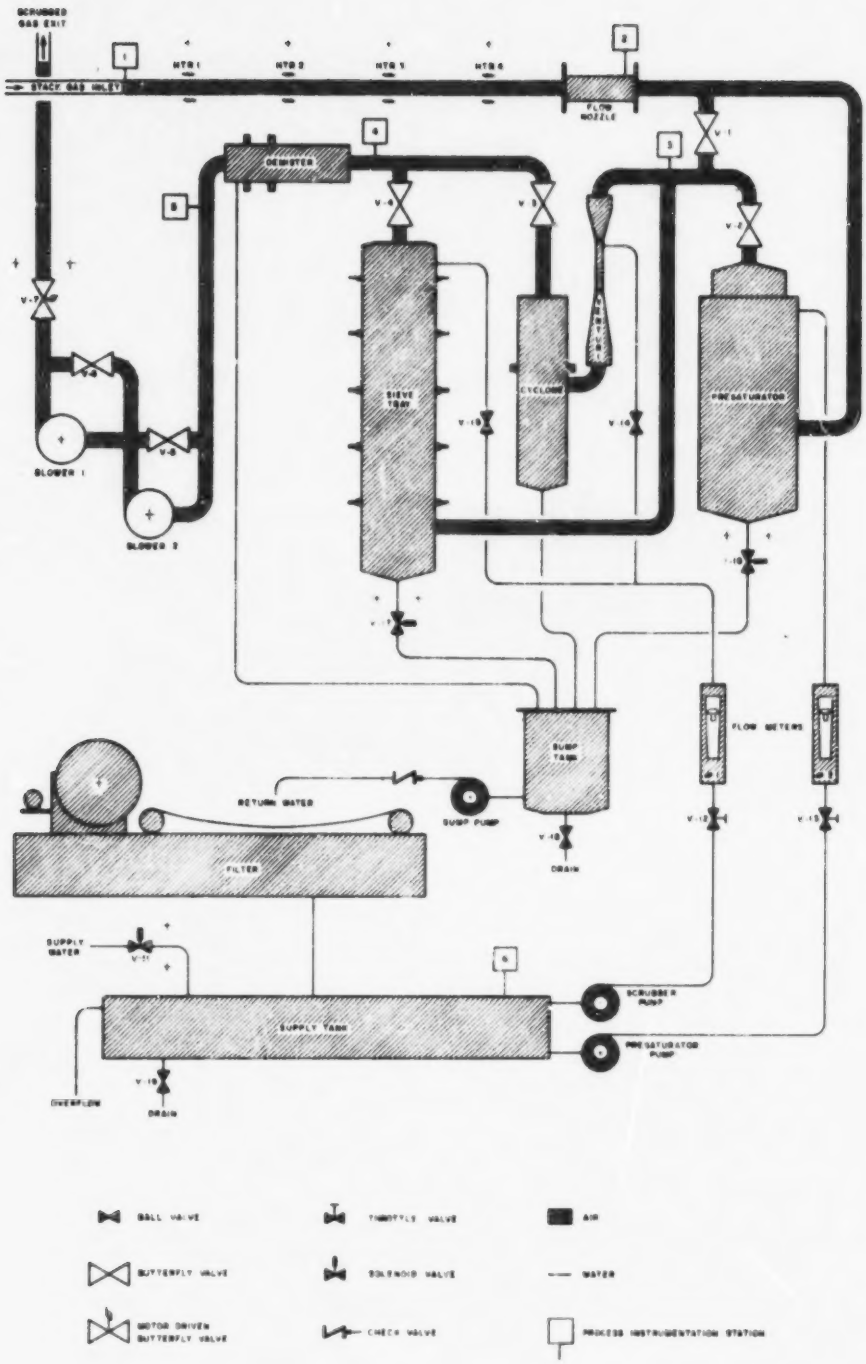

Figure 4. Mobile Scrubber
Flow Diagram

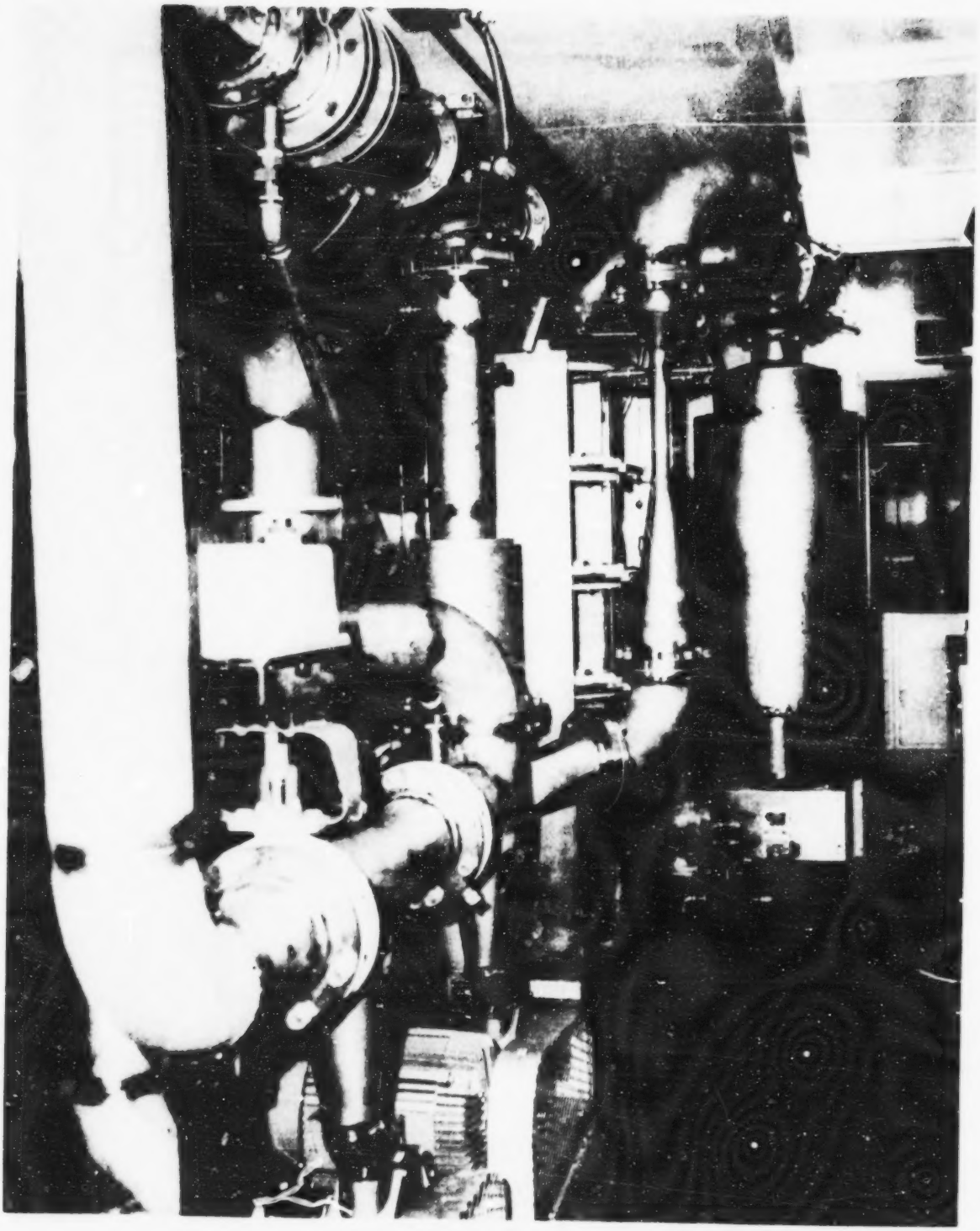

Figure 5. Mobile Scrubber Unit Process Area

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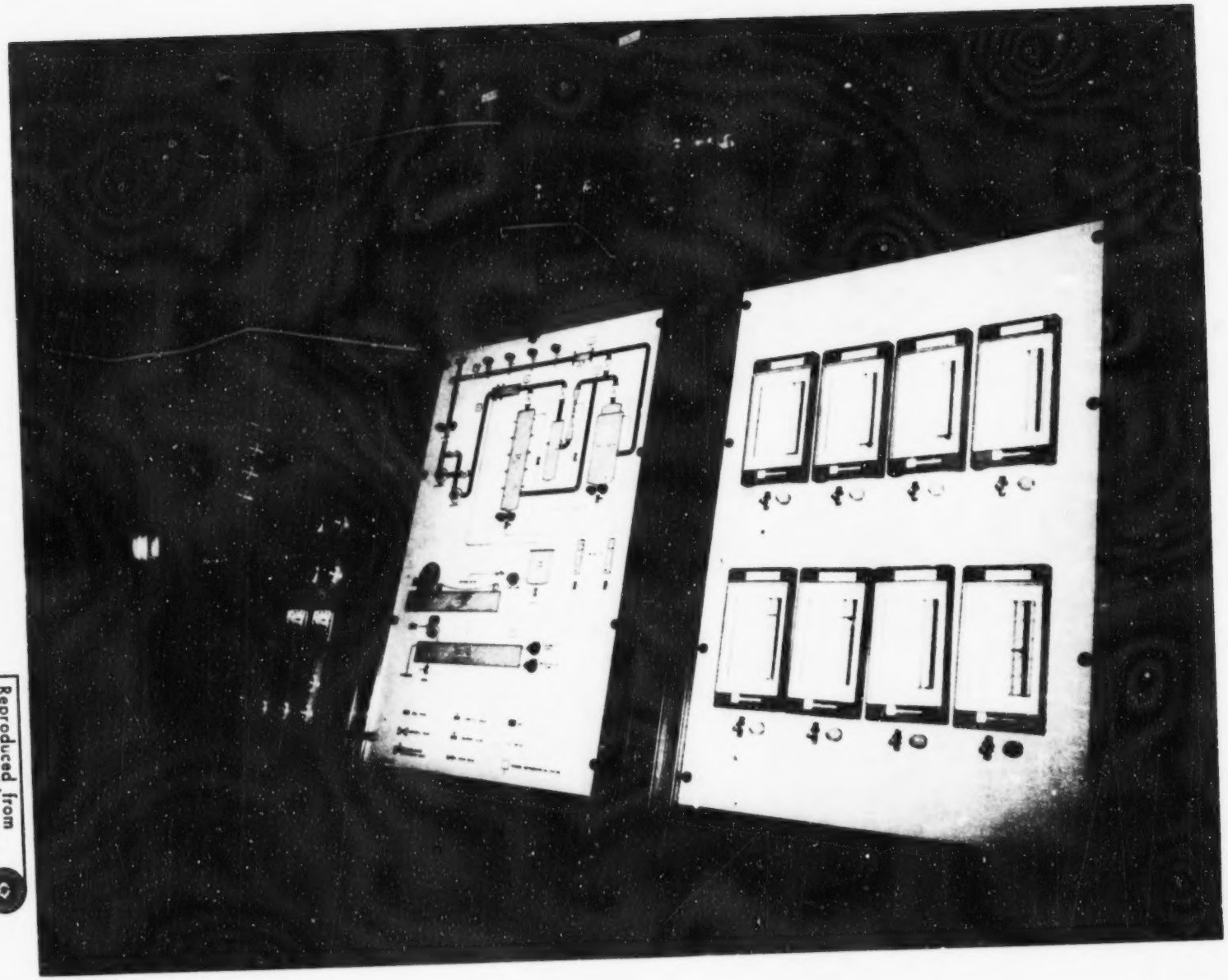

Figure 6. Control Panel

and evaporation of recirculating scrubber liquid when in closed loop mode. The presaturator can be bypassed when desired.

The demister is intended to collect both liquid and solid entrained in the scrubber exhaust, thus affording some protection to the high speed induction fans. A solids filter permits removal and disposal of particulate collected by the scrubbers when in closed loop circulation mode. In open loop mode, the filter minimizes solids load on the available external drainage system.

The gas duct entering the unit is equipped with in-line electric heaters to minimize gas temperature loss between the source and the scrubbers. A flow nozzle in the duct permits measurement of the gas rate to the scrubbers.

Liquid from all components noted flows to a sump tank, to the solids filter, to the supply tank, and then is recirculated through the scrubbers.

Figure 5 is a view of the process area looking forward in the trailer. In the foreground, on the floor, are the induction fans. Above them, near the ceiling, is the demister. Just beyond the fans is the venturi scrubber. Beyond this, and partially obscured, is the sieve tray scrubber. Forwardmost, just left of the control room door, is the presaturator. Figure 6 is a view of the control room panel.

Sieve Tray Scrubber

The sieve tray scrubber is a four-tray column in which liquid, fed to the downcomers in the top section, flows across each tray, over a weir into downcomers to the section below, collecting finally in a level-controlled bottoms chamber from which it drains to the sump tank.

Gas enters the bottom chamber, flows up through successive trays and discharges from the top scrubbing section. The column is shown in Figure 7.

Three sets of sieve trays, each with the same total open area, have hole sizes of 0.32 cm, 0.48 cm, and 0.64 cm, respectively. Since the liquid level on each tray, controlled by the fixed height of the inlet/outlet weirs, is nominally constant, regardless of liquid flow rate, and since the total open area of the three sets of sieve trays

is constant, pressure drop across the sieve tray column is mainly a function of the total gas flow rate and is relatively independent of tray hole size and liquid flow rate. This relationship is shown in the characteristic curves in Figure 8.

Venturi Scrubber

The venturi scrubber consists simply of a venturi throat section attached to a cyclone as shown in Figure 9. Scrubbing liquid is added to the throat about two inches below the throat entrance. Three interchangeable throat sections, each 30.5 cm long, have diameters 3.5 cm, 6.0 cm, and 8.5 cm. As expected, characteristic curves for each venturi throat, Figures 10 through 12, show pressure drop to be significantly dependent upon both gas and liquid flow rates.

Sunbury Shakedown Tests

The scrubber unit was taken, as received, directly from NSWC at Dahlgren, Va., to a generating station of Pennsylvania Power and Light Company at Sunbury, Pa., to undergo field shakedown testing. The 15 cm diameter ducting supplied with the unit was connected through a 15 x 10 cm reducer to a 10 cm port in the breaching of No. 1-A boiler, between the induced draft fans and the plant baghouse installation. Gas withdrawn from the breaching at this point contained 2300 - 6870 mg/m^3 of dust and about 1200 ppm SO_2.

A stepwise startup of the scrubber systems revealed no significant deficiencies or difficulties in overall functioning of systems and components. Within a matter of minutes, however, the pH of the liquid in the closed-loop curculating system dropped to about 1.7 and SO_2 gas-off from the solids filter made the process area of the trailer virtually uninhabitable. Opening the rear door of the trailer afforded little relief since an exhaust fan in the forward end of the process area carried SO_2 forward throughout the length of the process area (refer to Figure 13). Conditions in the control room were tolerable, however, and since the systems can be operated largely from this point, it was possible to proceed with characterizing the scrubbers with respect to flow and pressure drop.

In Figure 4 it is seen that the drain line from the venturi cyclone does not contain a valve. During operation of the

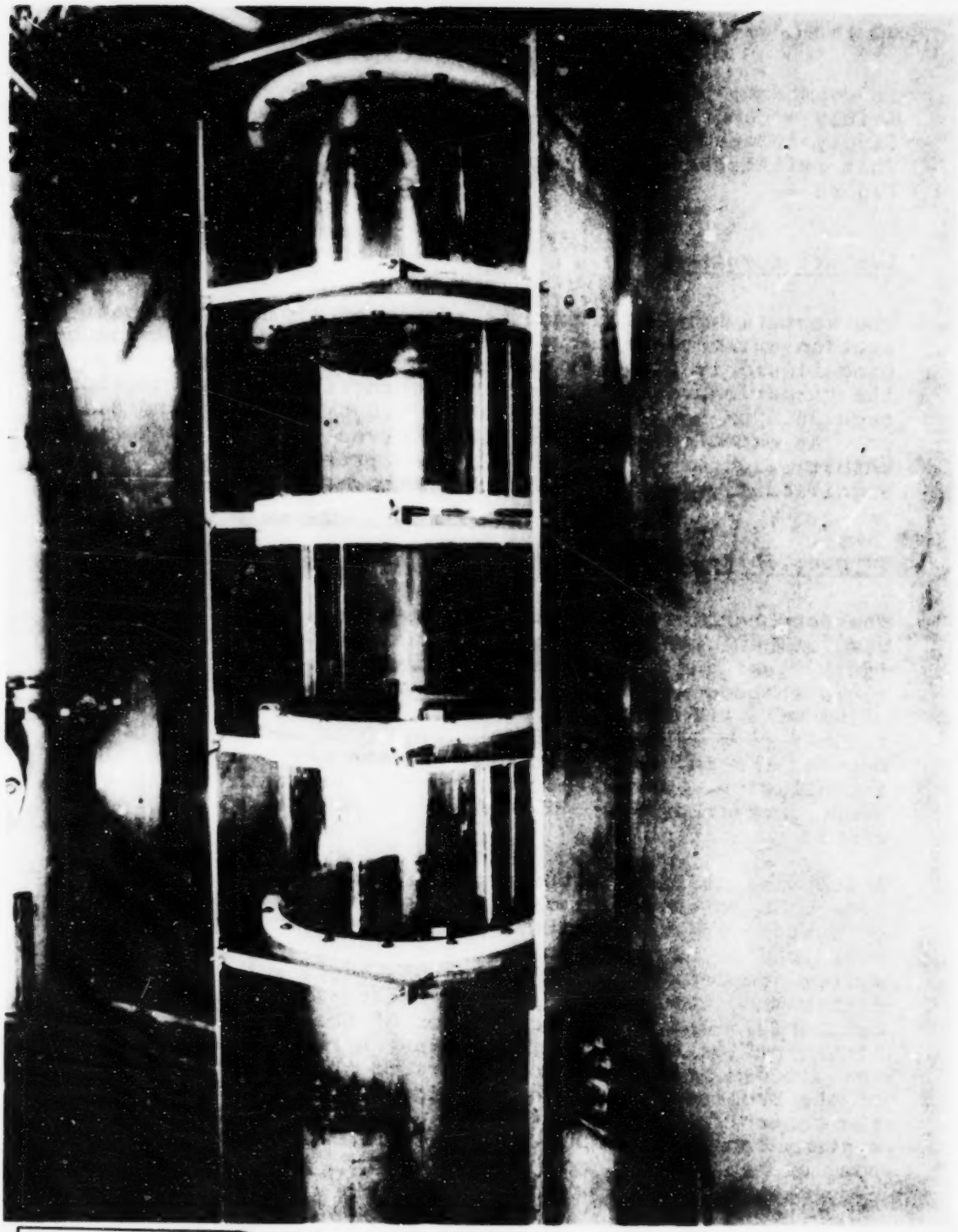

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Figure 7. Sieve Tray Column

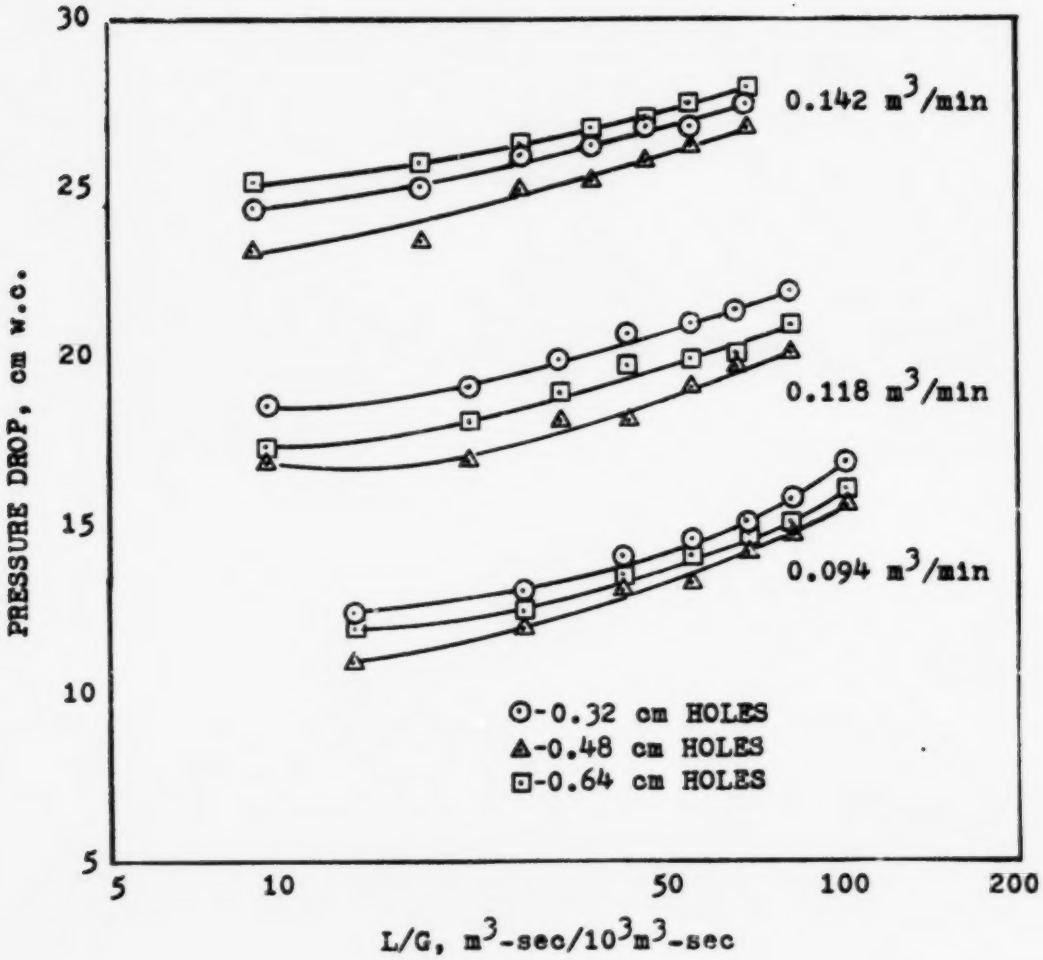


Figure 8. Sieve Tray Characteristic Curves

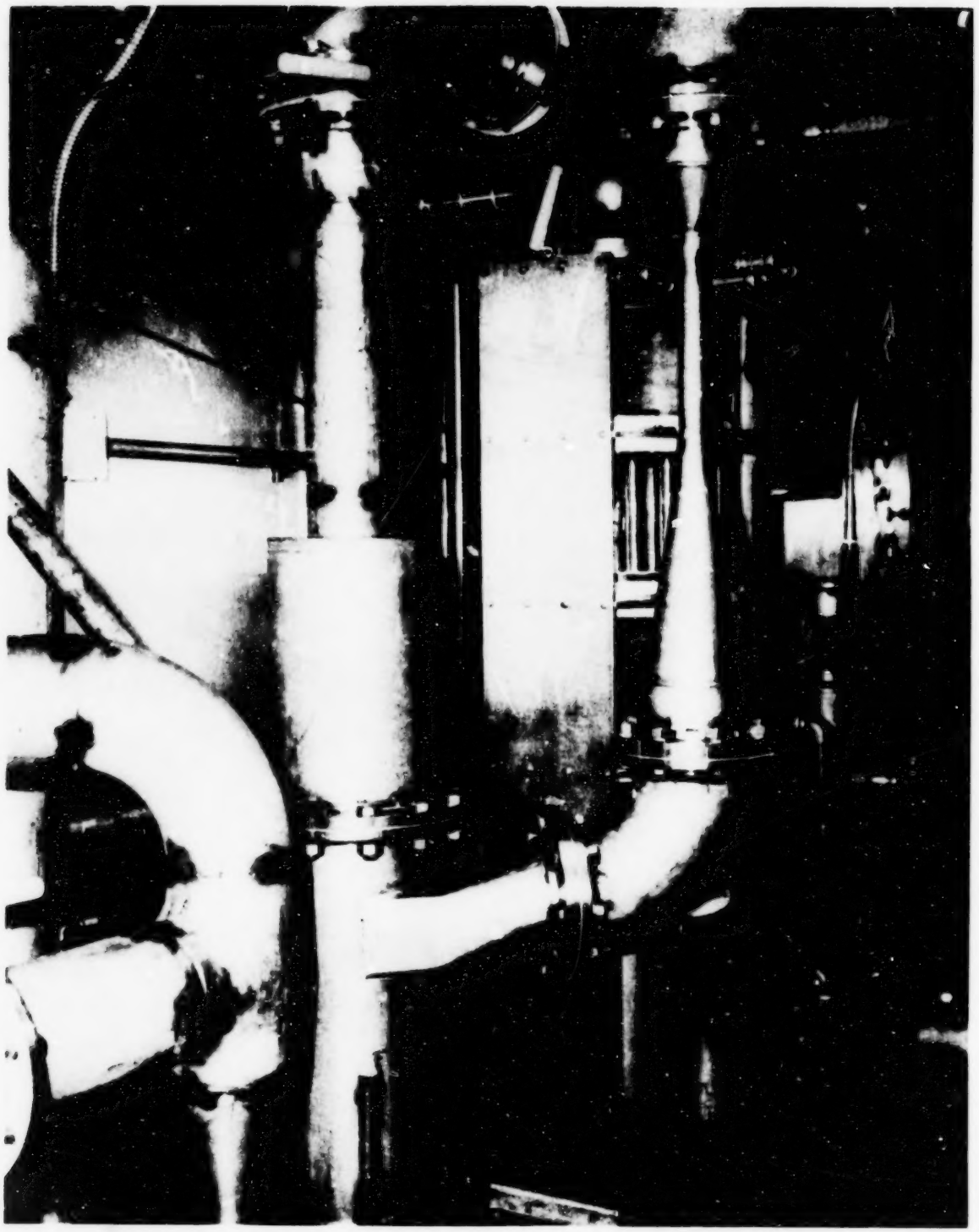


Figure 9. Venturi Scrubber

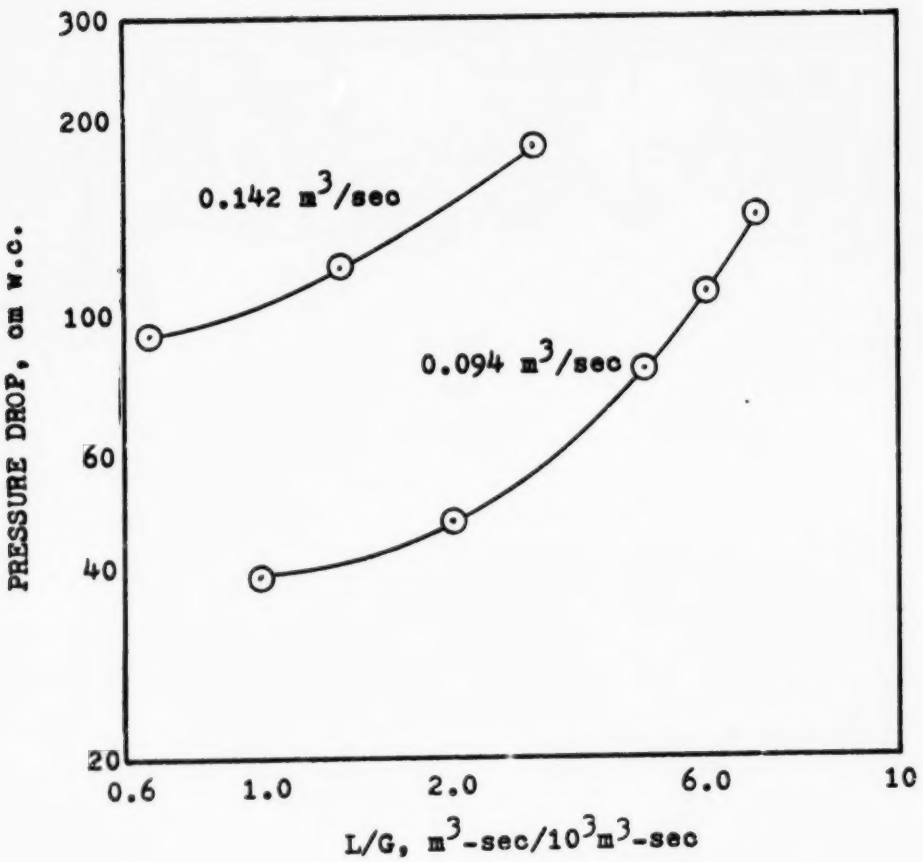


Figure 10. Characteristic Curves
Small Throat Venturi

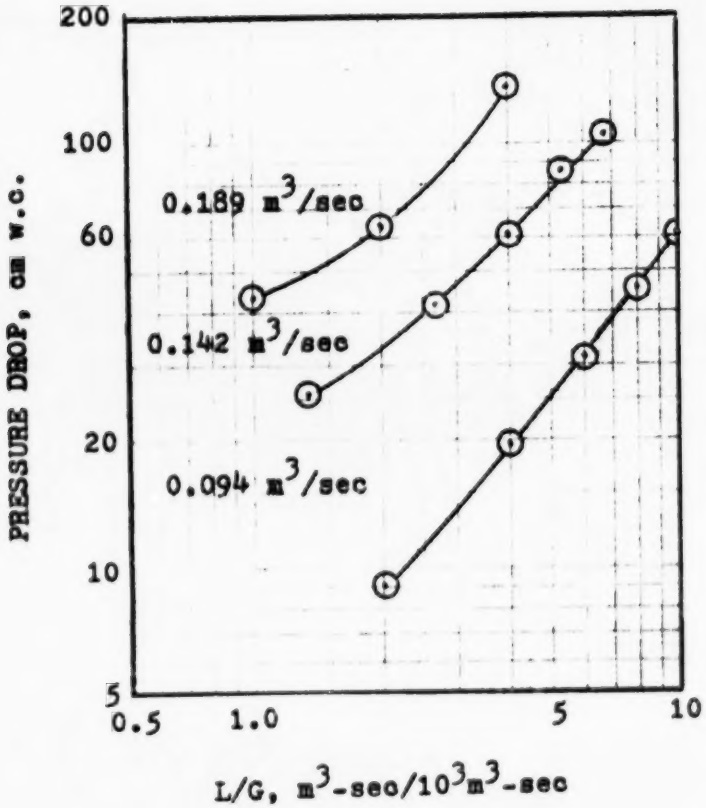


Figure 11. Characteristic Curves
Medium Throat Venturi

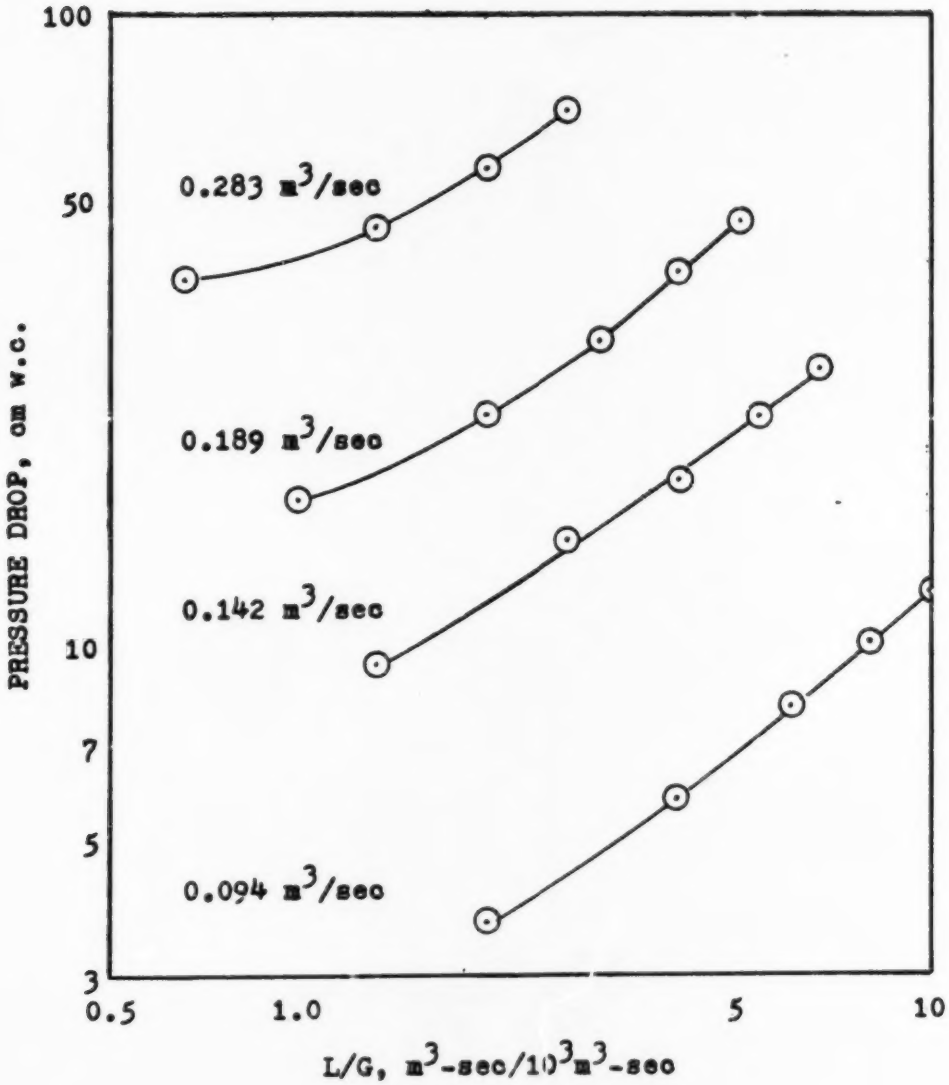


Figure 12. Characteristic Curves
Large Throat Venturi

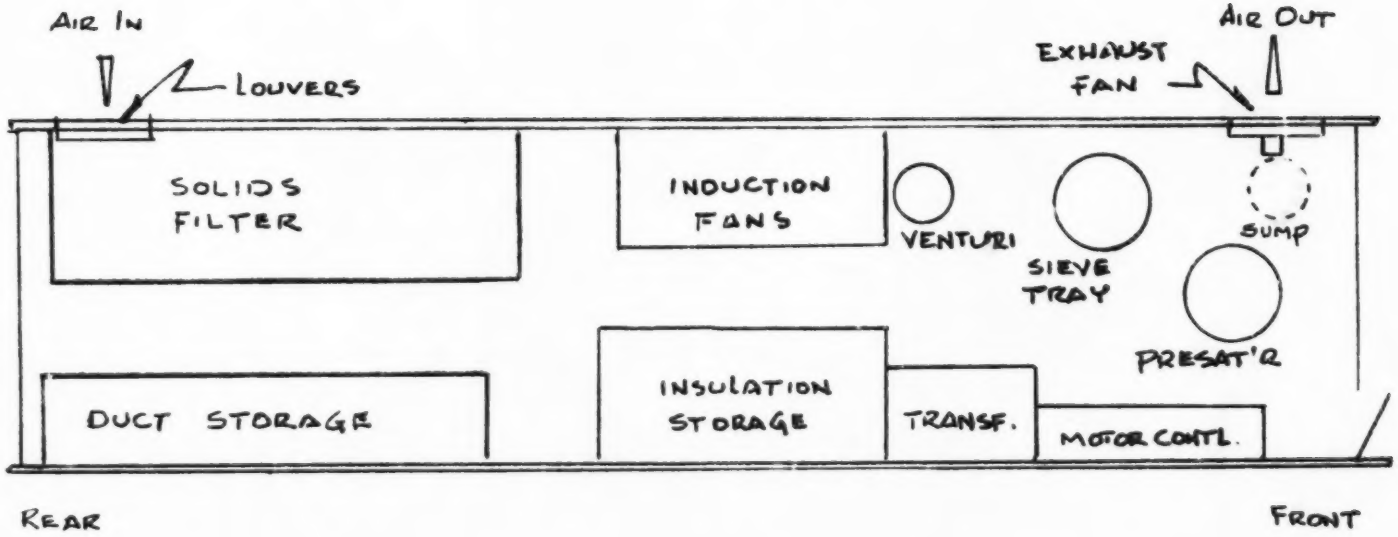


Figure 13. Schematic Plan of Scrubber Unit

sieve tray scrubber, considerable bypassing of gas through the venturi and cyclone to the sump tank was observed. The bypass vapor circuit in this case is: through the venturi and cyclone to the sump tank, up the demister drain line. This is a logical consequence of the fact that the demister drain line, which is not submerged at the sump tank end, taps in, at its upper end, at about the lowest pressure point in the system. Further, with a copious gas flow up the demister drain line, a downward flow of liquid would be strongly inhibited, if not prevented.

A manual valve was installed in the cyclone drain line to alleviate, in the field, the bypassing situation. However, it was not possible in the field to correct the demister drain line arrangement.

Within a week of operation, erratic, inconsistent, gas flow readings were observed and traced to accumulation of dust in the pressure taps in the flow nozzle (Figure 14). There was no way in the field to remedy this condition except to remove the nozzle section and clean out the dust accumulation.

Within two weeks of performance testing operations, the induction fans failed with severe damage to the fans. The apparent cause was accumulation of liquid in the fans from one or a combination of the following: condensation from saturated scrubber exhaust, penetration of mist through the mist eliminator, or failure of the mist eliminator to drain to the sump tank. The situation was aggravated by the fact that the liquid in the fans was extremely corrosive from absorption of SO_2.

The scrubber unit was returned to NSWC, who repaired the fans and attempted to analyze the cause of failure. They concluded that:

- Ball drive failures were caused by continuous water carry over from the scrubber system. This carry over in the gas stream increased the density of the medium (gas and entrained water) being pumped by the blower. An over-torque condition resulted, causing ball drive slippage (normally designed to roll except when short torque overloads occur). The increased friction caused overheating and spalling in the ball drive unit.

- Impeller failure was caused by a combination of erosion of the aluminum impeller by entrained particles in the high velocity gas stream, and high

torque loading on the rotor caused by large quantities of entrained water in the gas stream.

While these conclusions are valid as far as they go, they are not comprehensive of the total situation. For example, they make no mention of the highly corrosive environment to which the fans were subjected. The main problem with the fans is their inherent delicacy for such severe service. It is virtually impossible to prevent either liquid or solids from entering and accumulating in the fans, and in many instances the wet gas will be extremely corrosive.

In an effort to minimize entrained particulate carry over to the fans, NSWC installed a cartridge filter element between the mist eliminator and the fans. A vacuum bottle and pump were furnished to remove liquid collected by the element.

To mitigate the situation of SO_2 gas-off from the solids filter, NSWC completely enclosed the filter in opaque plastic film and installed a small fan to exhaust from beneath this covering through the trailer wall to the atmosphere.

Simulated Field Testing at RTP

When the scrubber unit was returned to the RTP, it was set up for extensive operational testing under simulated stack gas conditions, i.e., both fly ash and SO_2 were injected into the entering ambient air stream.

A significant point of interest during these tests was performance of the solids filter. At Sunbury, the filter passed a considerable amount of fines, and the filter cloth was observed to index frequently, presumably due to rapid blinding of the cloth. However, due to the short, intermittent operation at Sunbury, it was not possible to determine to what extent fines would accumulate in the scrubbing liquid, or what effect such condition would have. Neither was it possible to establish whether the apparent rapid blinding of the filter cloth was a transient or persistent effect.

Operation at RTP was also not long enough to settle the question of fines accumulation, but performance of the filter in regard to cloth blinding was quite satisfactory.

The major difficulty with the solids filter lay in its being totally wrapped in opaque plastic, which not only prevented observing its performance, but also prevented access to the

solids discharge hopper and other points of service. Consequently, this arrangement was completely removed and replaced with a plexiglass hood, which permits observation and access to service points, and provides for collection and discharge of gas-off from the filter liquid.

With the trailer exhaust fan arrangement as initially installed, air flow was from the back of the trailer forward. This flow was so strong as to cause the small filter exhaust fan to run backwards because of the draft entering through it from outside. The direction of rotation of the exhaust fan was reversed. This not only permitted the filter exhaust fan to function, but trailer ventilation was in the more desirable direction of front to rear.

The solenoid valve in the sieve-tray scrubber drain line became inoperative from deposition of fly ash in the pilot flow chamber and, generally, in the working parts of the valve. It was replaced by a manual valve with no interference in scrubber operation. It was anticipated the same fate would befall the solenoid valve in the presaturator drain, but it was decided to prove this in the field.

The flow patterns in the demister drain, sump tank, and in-line gas filter were revealed to be indiscriminate and inadequate. The sump tank had no vent, per se, the only vapor outlet being, as previously noted, up through the demister drain line. This arrangement effectively obviated liquid flow down the line to the sump tank and resulted in the in-line filter carrying the liquid burden from the demister. The vacuum drainage system provided for the in-line filter was inadequate to cope with this load. As noted earlier, the demister drain line terminus at the sump tank was not immersed but was flush with the top of the tank while all other liquid lines entered submerged.

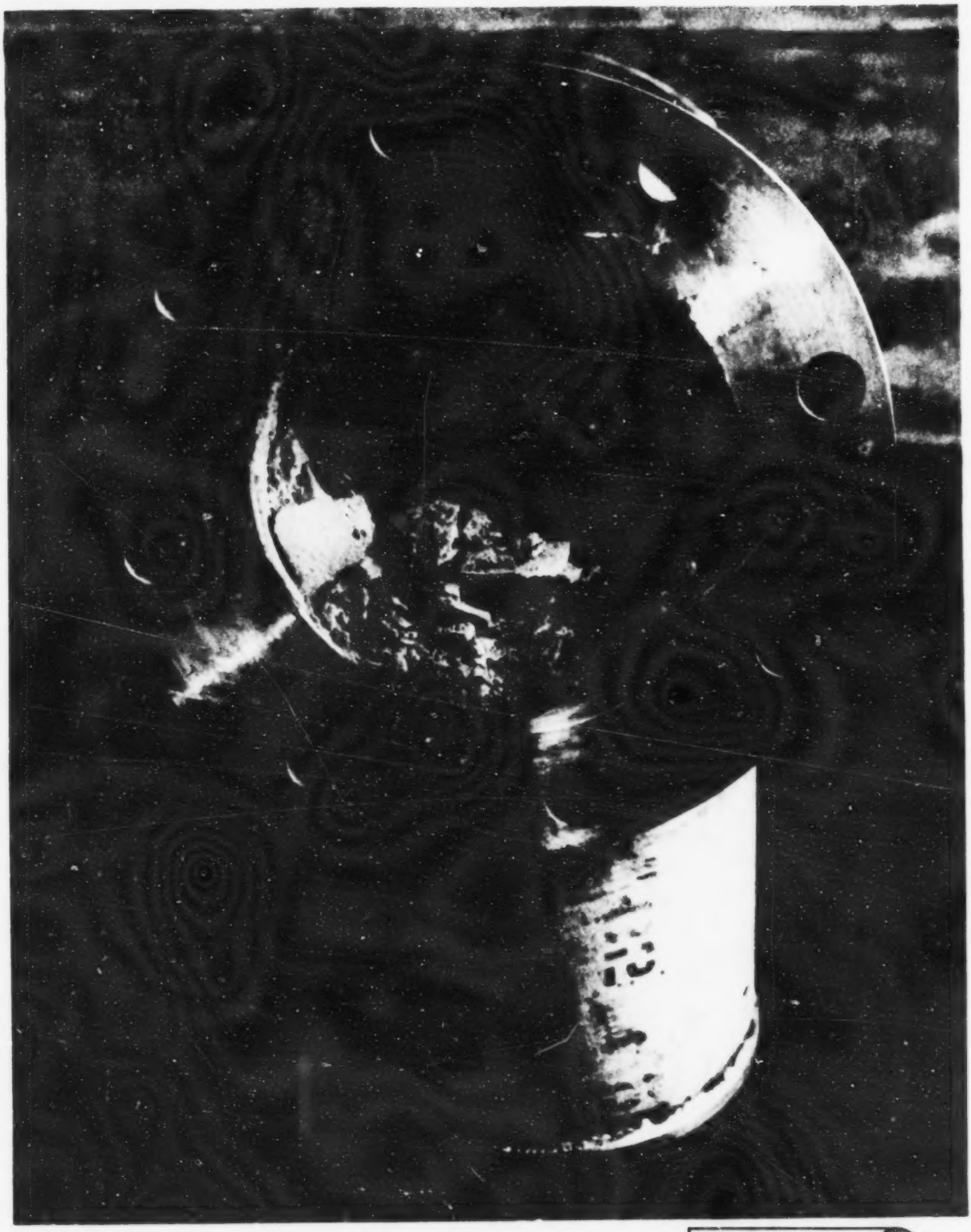
These interrelated lines were rerouted as follows. First, the demister drain line was teed into the presaturator drain line, which has a submerged terminus in the sump. This provided liquid seal against gas bypassing through the presaturator to the demister, since the total liquid head available for sealing is in excess of the system pressure. Second, a vapor vent line was installed from the former demister drain line tap, on the sump tank top, to a point downstream of the in-line filter. Since this point represents the lowest pressure point in the system, the sump tank is also at low pressure, encouraging all liquid flow in this direction while permitting separate vapor flow from the tank. Third, the vacuum-pump/vacuum-bottle arrangement for draining the in-line filter was replaced by a line from the filter

element to the sump tank with submerged discharge. Since, as noted, the sump tank is at the lowest pressure in the system, there is adequate driving force to drain the in-line filter to the sump tank. The revised system is shown schematically in Figure 15 for comparison with Figure 4.

During testing at RTP, erratic gas flow readings were again observed and, again, traced to dust accumulation in the flow nozzle differential-pressure taps. A series of air nozzles was installed around the circumference of the flow nozzle to permit short, frequent air blasts to clear out the dust accumulation. A small paint-spray compressor supplies the air blast.

Field Testing at Plymouth

On completion of testing and modifications at RTP, the scrubber unit was taken to Weyerhauser Corporation's pulp mill at Plymouth, N. C., and connected to the exhaust breaching of a lime recovery kiln. As expected, the solenoid valve in the presaturator drain line soon became inoperable from solids pluggage and had to be replaced by a manual ball-valve. Otherwise, at this writing, all systems are performing as expected. There has not, however, been sufficient operating time to reveal more obscure problems anticipated such as the effect of fines accumulation in the closed-loop scrubber-liquor system and pluggage of the Pall ring section in the presaturator.



Reproduced from
best available copy.

Figure 14. Dust Accumulation
in Flow Nozzle

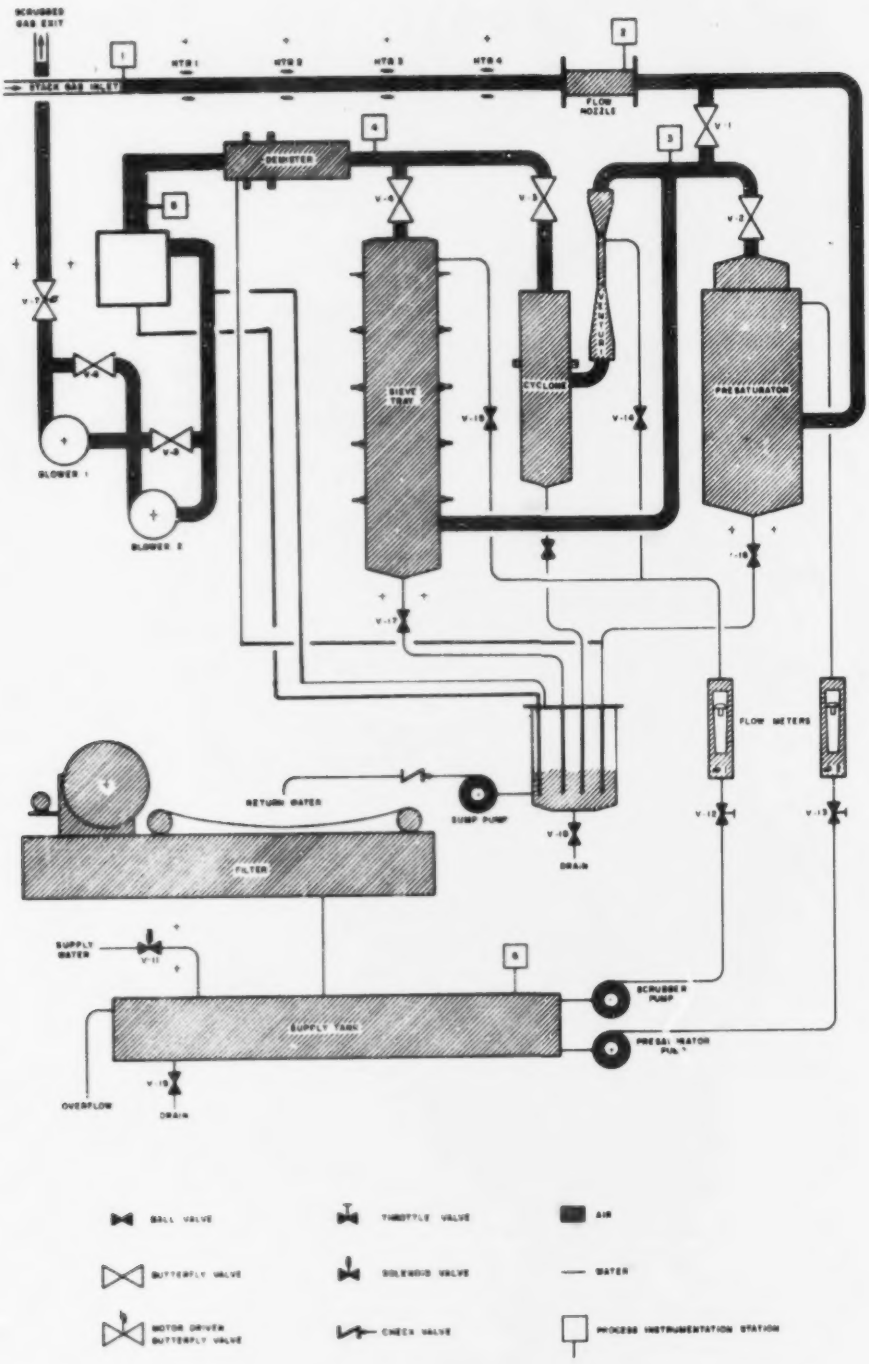


Figure 15. Revised Flow Schematic

V. REFERENCES

1. Hall, R. Mobile Fabric Filter System - Design Report. GCA/Technology Division. Contract No. 68-02-1075. October 1974.

2. Hall, R. Mobile Fabric Filter System - Final Report. GCA/Technology Division. Contract No. 68-02-1075. May 1975.

3. Opferkuch, R. E., S. P. Schliesser, and S. R. Turney. Mobile Baghouse Unit - Technical/Operations Report. Monsanto Research Corporation. Contract No. 68-02-1816. March 1975.

VI. APPENDIX A

BAGHOUSE MECHANICAL AND
OPERATIONAL DIFFICULTIES
ENCOUNTERED IN THE FIELD

Problem	Apparent Cause	Remedial Action	Site
1. Condensation -slipstream duct -baghouse -exhaust fan (see Figure 16)	a. Leakage (dilution) at duct joints (Morris couplings)	a. Plastic rubber sealant (Silastic) applied at duct joints	Plymouth
	b. Leakage at baghouse section flanges, glass windows, bag-shaker suspension rods, rotary valve in dust hopper discharge	b. All flanged joints sealed with plastic rubber, in the field. Subsequently, heavy asbestos gaskets provided for flanged joints. Could not cope with shaker rods in field. Subsequently provided rubber O-ring seals. Removed rotary valve and sealed outlet with blind flange.	"
	c. Conductive and radiant heat loss: duct, baghouse, exhaust fan	c. 3-1/2" fiberglass insulation applied on top of magnesia insulation. Baghouse exhaust duct and blower fiberglass insulated.	"
2. Flow controller failure	Ruptured bellows	Manual control with measurement by pitot tube. Replacement parts ordered for repair	Plymouth
3. Dust pluggage in discharge hopper	Dust bridging above rotary discharge valve. Probable causes: -moist solids -air leakage through rotary valve -inadequate hopper angle	Remove valve, seal with blind flange, manual cleanout. Subsequently added hopper vibrators	Plymouth

4.	Restricted flow rate through baghouse	Induction fan drive inadequate HP	Changing fan/motor pulley combination to achieve higher fan speed overloaded motor, circuit breaker. Subsequently replaced with larger drive	Plymouth
5.	High temperature controller failure	Both high and low temperature controllers wired wrong. High temperature controller burned out	Controllers rewired but only low temperature controller operative	"
6.	Lack of accessability to control console circuitry	Poor design	None with present product. Console must be virtually disassembled to troubleshoot and repair	"
7.	Induction fan out of balance	Solids deposits on, corrosion of wheel	Removed wheel, sandblasted, rebalanced	Sunbury
8.	Failure of bag differential pressure indicator recorder	Unknown	Use Magnehelic gauges to indicate	"
9.	Dust pluggage in discharge hopper	Solids bridging above rotary discharge valve. Vibrators ineffective	Remove valve, seal with blind flange, manual cleanout	"
10.	SO_2-laden gas contaminating work area	Gas leakage around flow control damper (positive pressure point in system)	Personnel wear respirators. Could not seal as shaft must be free to rotate. Subsequently moved damper to negative pressure point in system	"
11.	Unable to install felt bags	Bag hangers could not accept thickness of felt bag material	Bags notched to adapt to hangers. Subsequently, new hangers designed, installed	"
12.	Gate valves sticking	Solids deposits on moving gate parts and seats prevented full closure or resistance to movement from a set position	Rapping valve assembly with hammer, disassembly and cleaning	"

13.	Malfunction of flow control damper	Loose linkages between controller and damper	Linkages adjusted	Plymouth
14.	Reverse flow fan failure	Plastic wheels deformed from high temperature	None. Metal wheel replacements planned	"
15.	Dust pluggage in discharge hopper	Dust bridging above rotary discharge valve	Hopper kept at elevated temperature by heat tapes permitted solids flow	"
16.	Gate valves inoperable	Solids deposits on moving gate parts and seats froze position	Disassemble and clean. Require redesign	"

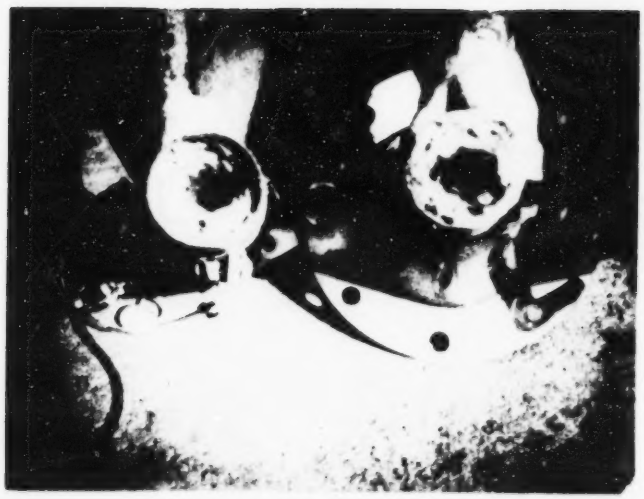


Figure 16. Mud Deposit in Induction Fan Inlet

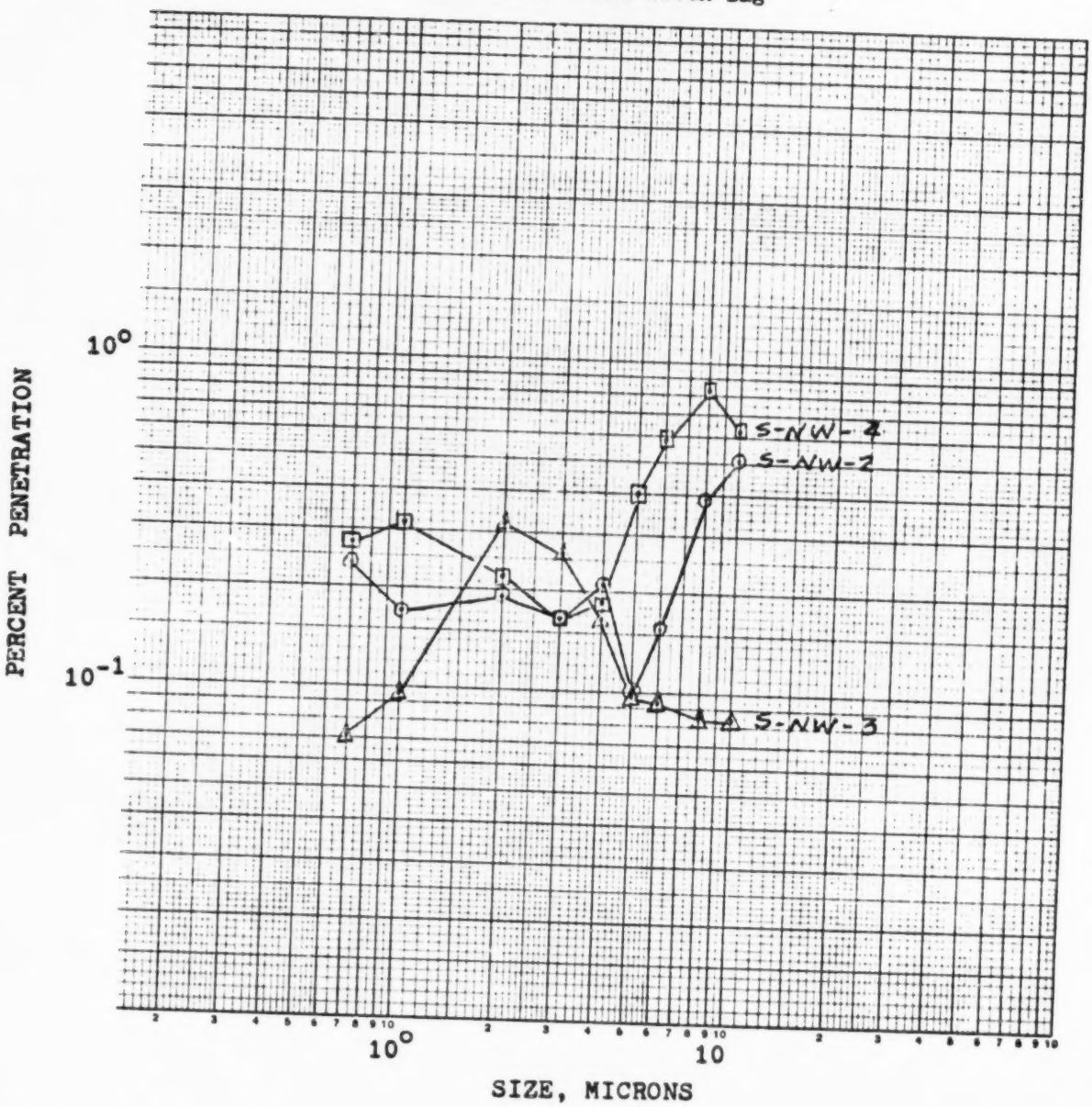
VI. APPENDIX B

Graphs of Percent Penetration

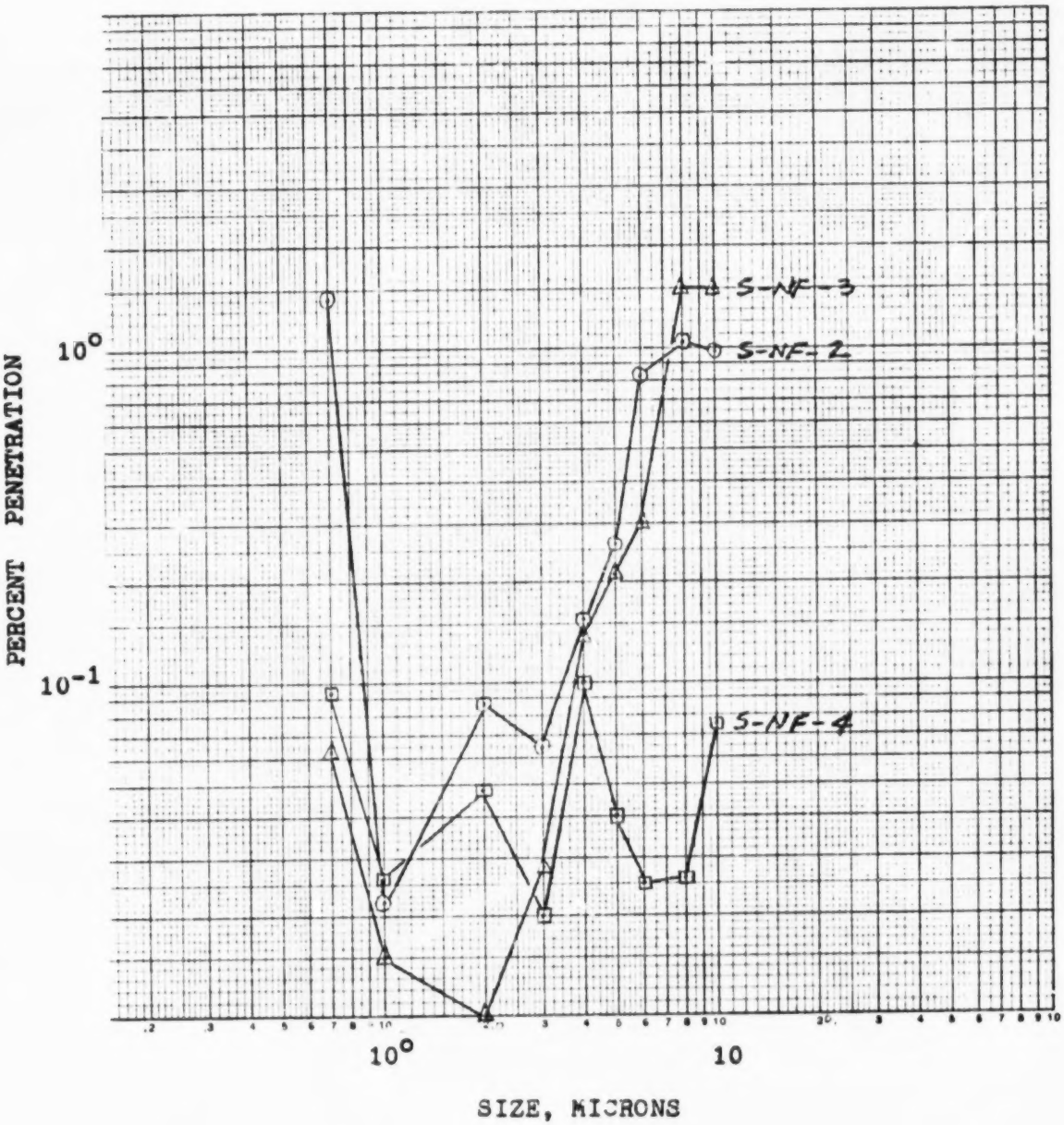
by

Particle Size

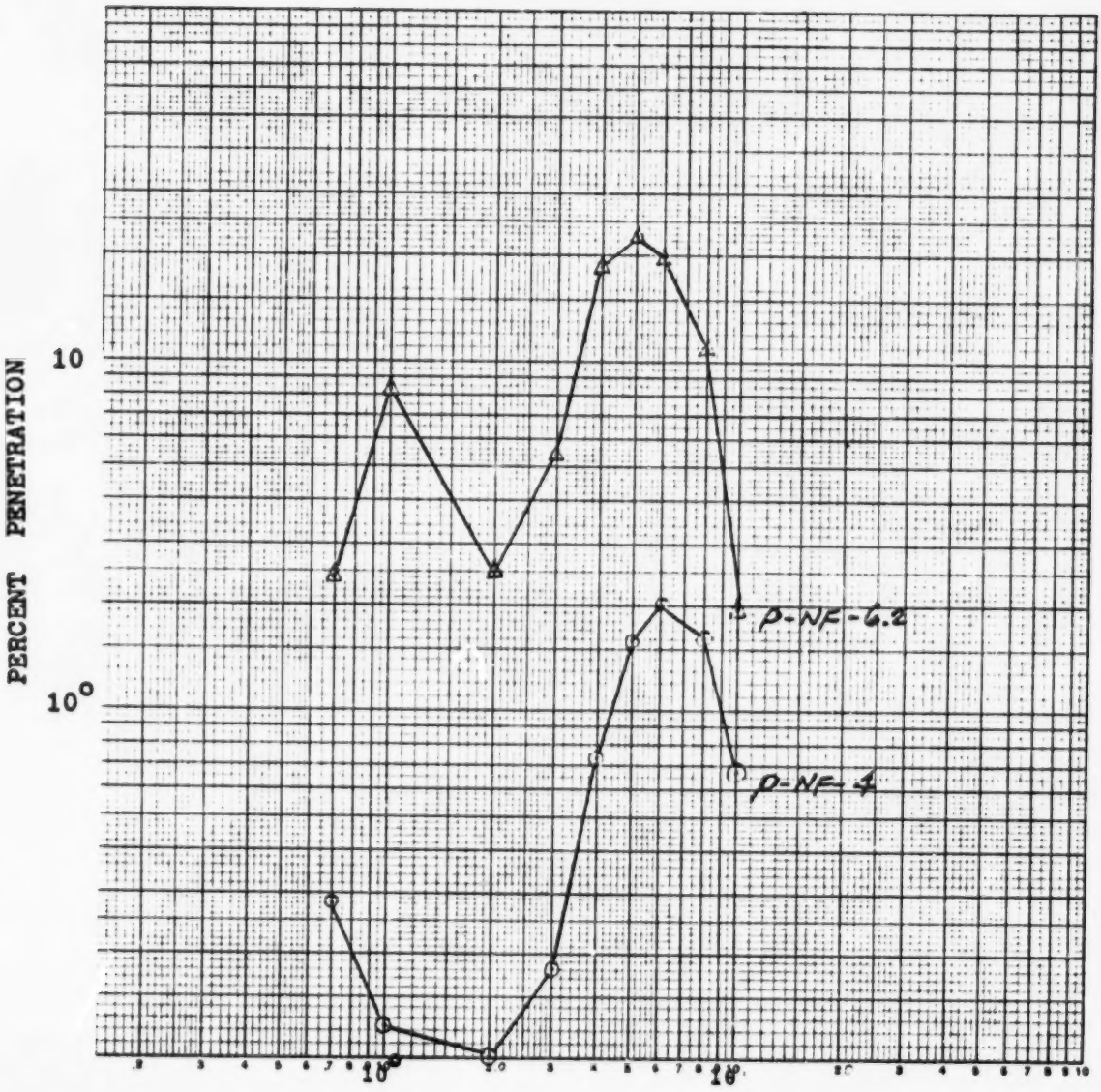
Percent Penetration by Particle Size
EFFECT OF AIR/CLOTH RATIO
Shake Mode, Nomex Woven Bag



Percent Penetration by Particle Size
EFFECT OF AIR/CLOTH RATIO
Shake Mode, Nomex Felt Bag

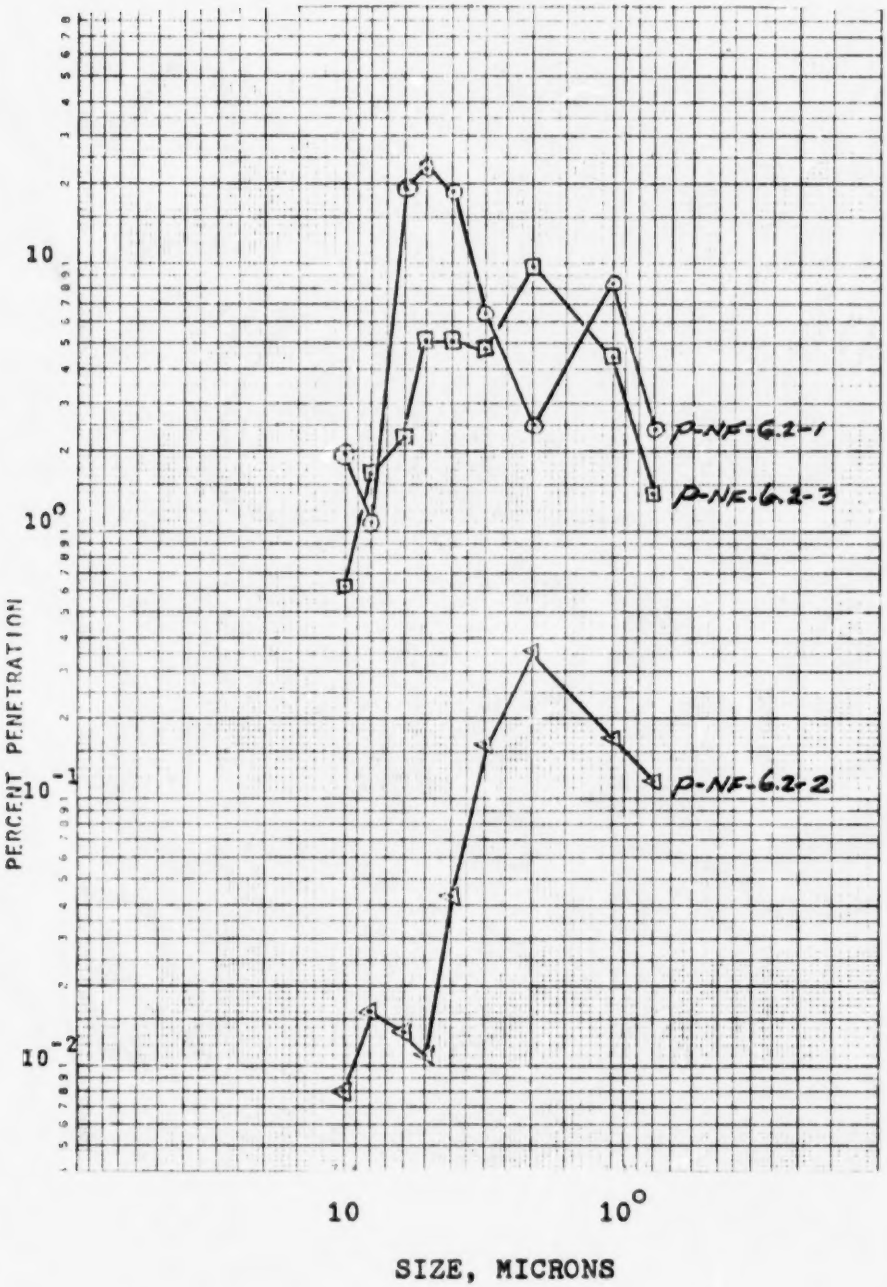


Percent Penetration by Particle Size
EFFECT OF AIR/CLOTH RATIO
Pulse Mode, Nomex Felt Bag

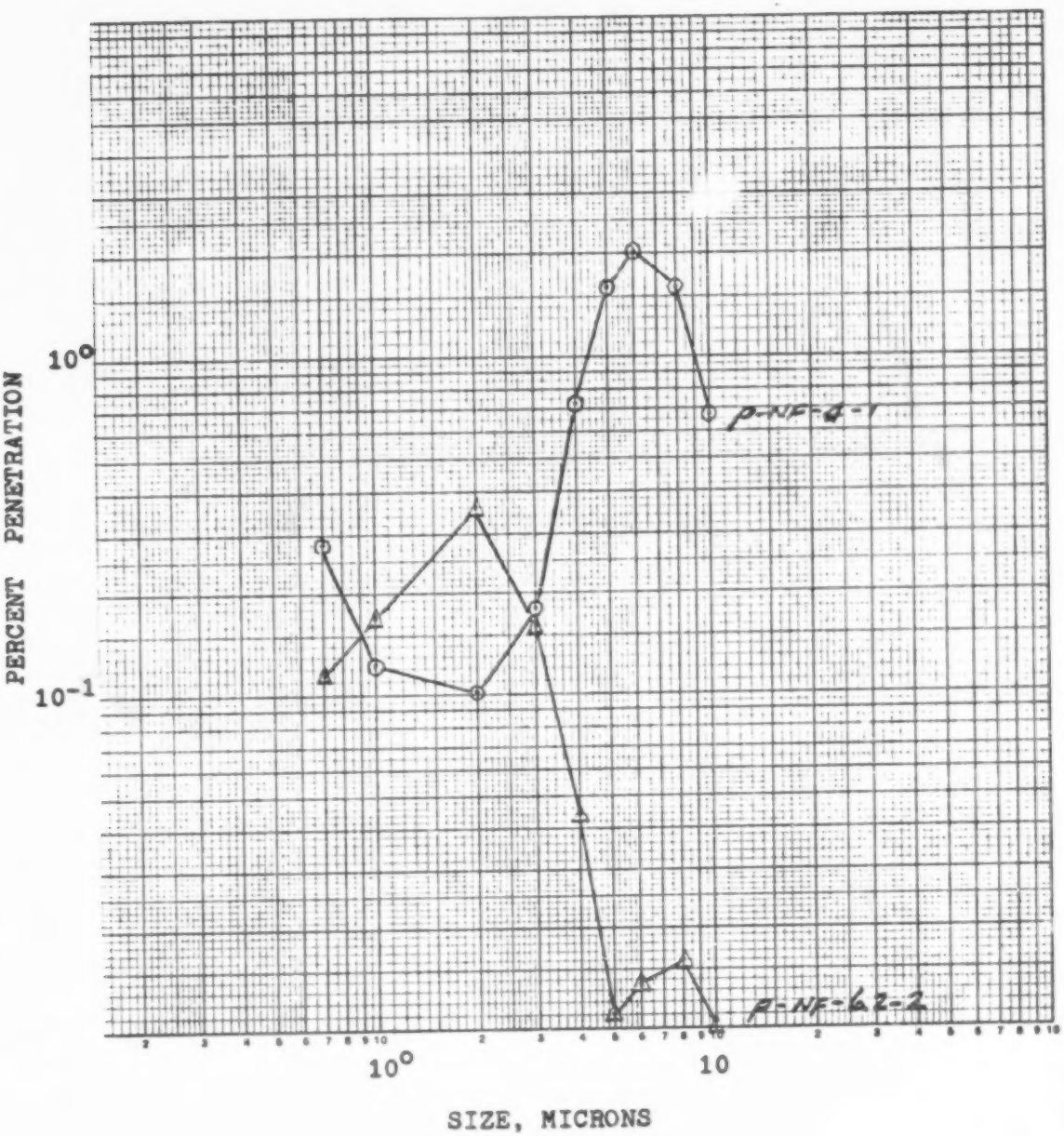


SIZE, MICRONS

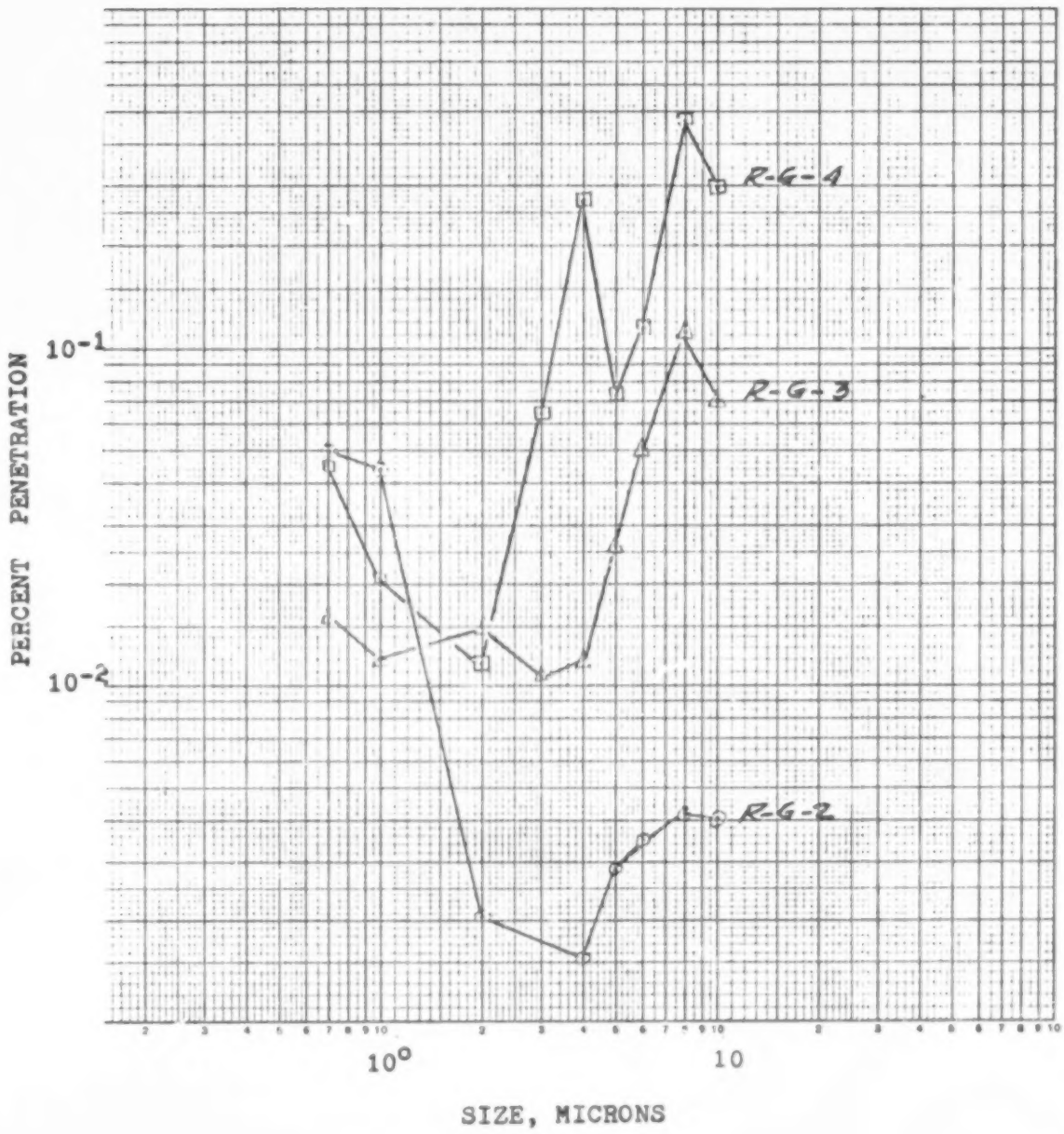
Percent Penetration by Particle Size
EFFECT OF PULSE INTERVAL
Pulse Mode, Nomex Felt Bag



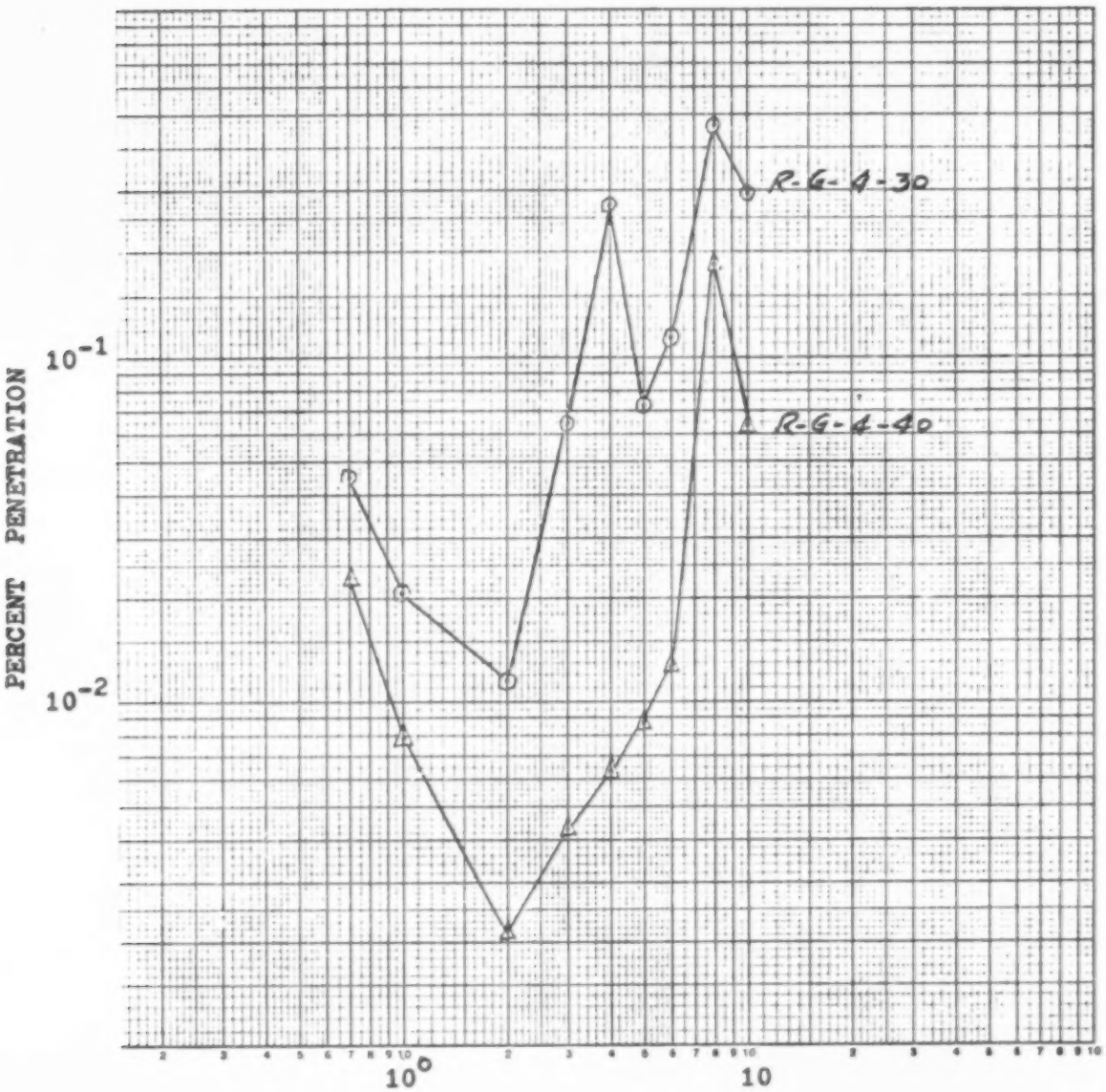
Percent Penetration by Particle Size
EFFECT OF AIR/CLOTH RATIO
AND PULSE INTERVAL



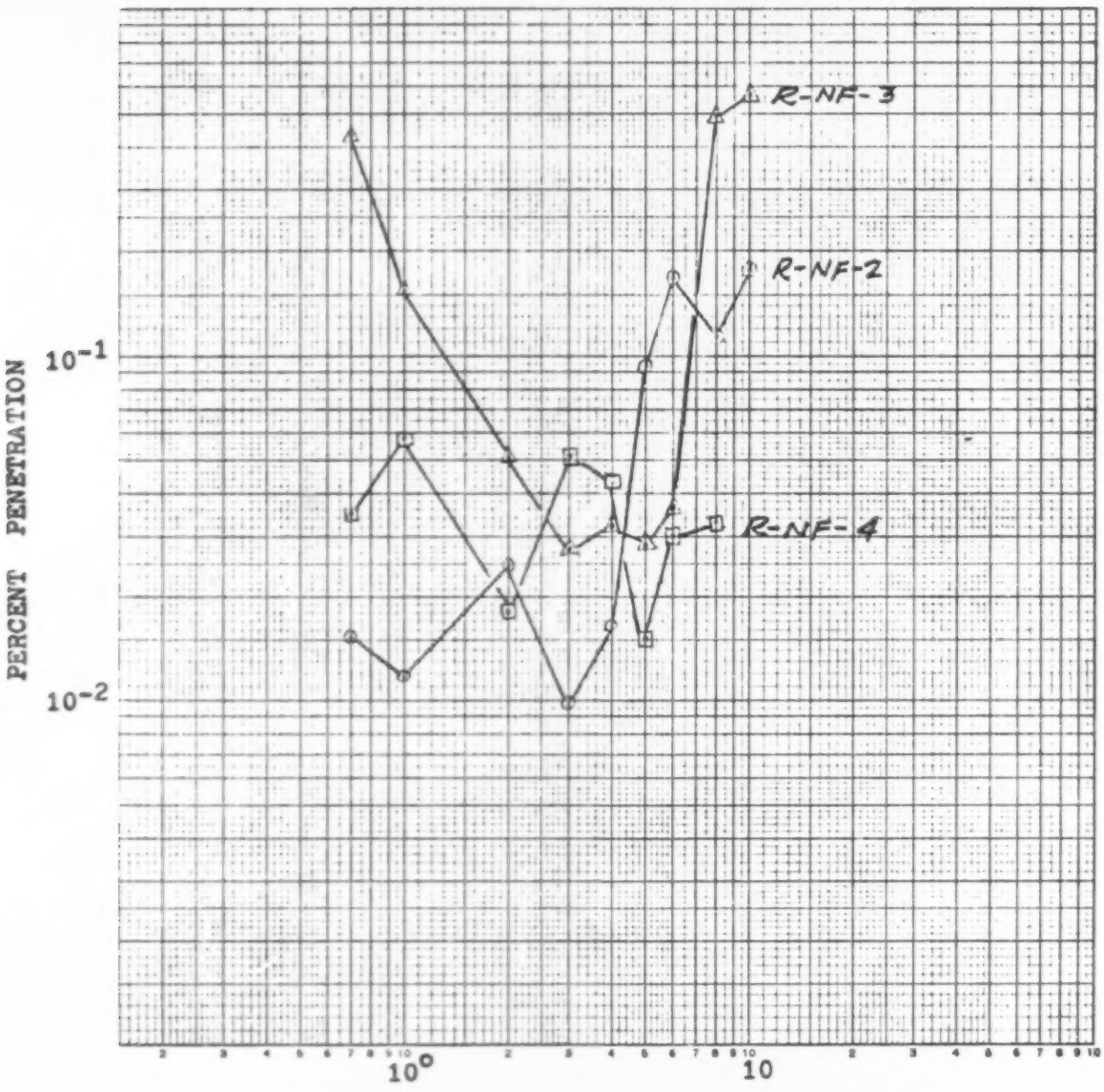
Percent Penetration by Particle Size
EFFECT OF AIR/CLOTH RATIO
Reverse Mode, Glass Bag



Percent Penetration by Particle Size
EFFECT OF FILTRATION TIME
Reverse Mode, Glass Bag



Percent Penetration by Particle Size
EFFECT OF AIR/CLOTH RATIO
Reverse Mode, Nomex Felt Bag



Percent Penetration by Particle Size
EFFECT OF FILTRATION TIME
Reverse Mode, Nomex Felt Bag